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ORIGINAL ARTICLES.

I.—Note on the Antlers of a Red-Deer (*Cervus elaphus*, Linn.) from Alport, Youlgreave, near Bakewell, Derbyshire—now in the British Museum (Natural History), Cromwell Road, London.

By Henry Woodward, LL.D., F.R.S., V.P.G.S., etc.

(PLATE II.)

In 1891, Frank S. Goodwin, Esq., of Bakewell, Derbyshire, presented to the British Museum (Natural History) a pair of antlers of red-deer, with fragments of the calvarium attached, which had been obtained, with other cervine remains, from a tufaceous deposit of comparatively modern date near Bakewell, Derbyshire.

Owing to the loss of all animal matter the antlers were in a very friable condition and fell in pieces on being handled, although at some distant time they had been repaired partially with long strips of calico.

Two causes rendered them of interest: firstly, they were of unusually large size, resembling the great American Wapiti (*Cervus Canadensis*) in stoutness and length of beam; secondly, they proved to have been described in a letter from the Rev. Robert Barber, B.D., to John Jebb, Esq., M.D., F.R.S., which was published in the Phil. Trans. Royal Society for 1785 (vol. lxxv, p. 353).

Notwithstanding their almost hopeless state of dilapidation, they attracted the attention of Sir Edmund Giles Loder, Bart., and Mr. J. G. Millais (the latter of whom examined and made drawings of them about a year ago). An attempt was made to bring the broken antlers together again; and after much time and labour expended by Mr. C. Barlow, the Formatore, they have at length been successfully rehabilitated, and are now exhibited on the top of pier-case No. 16, in the Geological Gallery devoted to fossil Mammalia, where they form, from their size and whiteness, one of the most striking objects in the series of cervine remains.

The following is the account printed in the Phil. Trans. R.S. for 1785 (vol. lxxv, p. 353), read April 14th, 1785:—

"About five years ago, some men working in a quarry of that kind of stone which in this part of the country we call 'tuft' [tufa],[1] at about five or six feet below the surface, in a very solid part of the rock, met with several fragments of the horns [antlers] and bones of one or different animals.

"Amongst the rest, out of a large piece of the rock which they got entire, there appeared the tips of three or four horns [antlers] projecting a few inches from it, and the *scapula* of some animal adhering to the outside of it. A friend of mine, to whom the quarry belongs, sent the piece of the rock to me, in the state they got it, in which I let it remain for some time.

"But suspecting that they might be tips of the horns [antlers] of some head enclosed in the lump, I determined to gratify my curiosity by clearing away the stone from the horns [antlers]. On doing which, I found that the lump contained a very large stag's head, with two antlers upon each horn, in very perfect preservation, inclosed in it.

"Though the horns [antlers] are so much larger than those of any stag I have ever seen, yet, from the sutures in the skull appearing very distinct in it, one would suppose that it was not the head of a very old animal.

"I have one of the horns nearly entire, and the greatest part of the other, but so broken in the getting out of the rock, that one part will not join to the other, as the parts of the other horn [antler] do.

"The horns [antlers] are of that species which park-keepers in this part of the country call 'throstle-nest horns,' from the peculiar formation of the upper part of them, which is branched out into a number of short [tines or] antlers which form a hollow about large enough to contain a thrush's nest.

"I send you the dimensions of the different parts of them, compared with the horns [antlers] of the same species of a large stag which have probably hung in the place from whence I procured them, two or three or perhaps more centuries; and with another pair of horns [antlers] of a different kind which are terminated by one single pointed antler and which were the horns [antlers] of a seven-year-old stag [*Cervus elaphus*].

"The river Larkell runs down the valley, and part of it falls into the quarry where these horns [antlers] were found, the water of which has not the property of incrusting any bodies it passes through.

"It is therefore probable that the animal to which these horns [antlers] belonged was washed into the place where they were found, at the time of some of those convulsions which contributed to raise this part of the Island out of the sea.

"Besides this complete head, I have several pieces of horns, bones (particularly the scapula I mentioned above), and several vertebræ of the back found in the same quarry; some, if not all, of them probably belonging to the animal whose head is in my possession.

[1] Tuft (*tufa*) is a stone formed by the (calcareous) deposit left by water passing through beds of sticks, roots, vegetables, etc., of which there is a large stratum at Matlock Bath, in this county.

'Dimensions of the Horns [Antlers] found at Alport.

	ft.	ins.
Circumference at their insertion into the corona		$9\frac{7}{8}$
a. Length of the lowest antler [brow-tine]	1	2
b. Length of the second antler [bez-tine]		$11\frac{1}{2}$
c. Length of the third antler [trez-tine]	1	$1\frac{1}{2}$
Length of horn antler [in the beam]	3	$3\frac{1}{2}$

Dimensions of Large Pair of 'Throstle-nest Horns' (ordinary Red-Deer Antlers).

	ft.	ins.
Circumference at their insertion into the corona		7
a. Length of the lowest antler [brow-tine]	1	0
b. Length of the second antler [bez-tine]		$10\frac{1}{8}$
c. Length of the third antler [trez-tine]		$11\frac{1}{2}$
Length of horn antler [in the beam]	2	$7\frac{1}{2}$

Dimensions of the Horns of a Stag Seven Years Old.

	ft.	ins.
Circumference at their insertion into the corona		$5\frac{1}{2}$
a. Length of the lowest antler [brow-tine]		9
b. Length of the second antler [bez-tine]		10
c. Length of the third antler [trez-tine]		10
Length of horn antler [in the beam]	2	$8\frac{3}{4}$

"*Youlgreave, January 23rd*, 1785."

P.S.—The following measurements have been taken since the antlers have been repaired and mounted in the Gallery.[1]

Measurement of Antlers of *Cervus elaphus* from Alport, Youlgreave.

	ft.	ins.
Width at the "nests"	3	9
Length of right antler	4	0
,, ,, left ,, ...	3	8
,, ,, brow-tine		11
,, ,, 2nd ,, ...	1	0
,, ,, 3rd ,, ...	1	1
Girth of pedicle		$7\frac{1}{4}$
,, above the burr		$9\frac{3}{4}$
,, ,, 1st tine		$9\frac{1}{4}$
,, ,, 2nd ,, ...		$6\frac{1}{2}$
,, ,, 3rd ,, ...		$6\frac{1}{4}$

II.—The Lakes of Snowdon.

By J. E. Marr, M.A., F.R.S., and R. H. Adie, M.A., F.C.S., Lecturers of St. John's College, Cambridge.

THE waterways of Wales owe their directions to a complex series of events which it is not our province to discuss in this place, but the minor features of Snowdonia are largely determined by planes of weakness which were produced in the rocks of the region during the occurrence of the marked earth-movements at the close of Silurian and Carboniferous times. The Post-Silurian earth-movements gave rise to planes of weakness running in a general north-east and south-west direction, and in a direction at right angles

[1] See also "British Deer and their Horns," by J. G. Millais, p. 96, fig. 2, and p. 105. (Roy. 4to; Sotheran & Co., 1897.)

to this. Amongst other features parts of the coastlines of Anglesey are determined by these planes of weakness. The Post-Carboniferous planes run approximately north-and-south and east-and-west. The Glaslyn below Beddgelert runs generally along a north-and-south plane and the Capel Curig Valley along one extending in an east-and-west direction.

The Snowdon mass, with its northern prolongation forming the Moel Eilio range, is of a rectangular shape. It is about ten miles long, and has an average width of about four miles. The ridge runs in a general north-west and south-east direction, whilst the ends are at right angles to this, for the Snowdon mass is bordered by depressions coinciding with planes of weakness produced during the Post-Silurian period of earth-movement. On the north-east side the mass is bounded by the upper portion of the Seiont Valley, containing the two lakes of Llanberis; on the south-west side by the upper part of the Gwrfai Valley, holding the lakes of Cwellyn and Llyn-y-gader, and the head of Nant Colwyn; the south-eastern boundary is formed by the Vale of Gwynant, with Llyn Gwynant and Llyn-y-ddinas; and on the north-west is a portion of the Seiont, east of Carnarvon, which has worn its bed along the soft Arenig shales. Of ridges determined by the Post-Silurian changes, the prevailing one is that which runs north-west and south-east from Moel Eilio, through Moel Goch and Moel Cynghorion, over the summit of Snowdon, and is continued to the south-west as the buttress of Lliwedd. At right angles to this is the ridge of Crib-y-ddysgl, and also the ridge running from Snowdon on the Beddgelert side known as Llechog, part of which, however, runs parallel to the north-west and south-east system, as does also the ridge which culminates in the peak of Yr Aran. Of the ridges determined by the north-and-south and the east-and-west planes of weakness, the most important are that of Crib Goch, which runs east and west, and that extending between Snowdon and Y Geuallt, which is at right angles to this. Bounded by these ridges and others having the same general directions, lie the six beautiful cwms of Snowdon, four of which contain one or more lakelets. We have laid stress upon the planes of weakness, because they contribute some information concerning the origin of the lakelets. The south-eastern and south-western shores of Llyn Llydaw are defined by two Post-Silurian planes of weakness. In the cwm on the west side of Snowdon, the three upper tarns, Llyn Glas, Llyn Coch, and Llyn-y-nadroedd, occur on a north-east and south-west line; the stream from the central one, Llyn Coch, runs at first along a north-west and south-east line, and this, if continued, runs along the long axis of Llyn Ffynnon-y-gwas.

The principal precipices of Snowdon occur on the north-east side, and the same feature is seen in the case of the Glyder range; and in the Lake District the east side of the Helvellyn and High Street ranges is the precipitous one. Minor examples may readily be called to mind showing a precipitous eastern slope and gentle western one, and the cases are too frequent to be merely accidental. It is possibly due to the rainfall from the south-west, and the south-

westerly aspect of the slopes causing much vegetation to grow on the south-west faces of the hills and giving rise to peat-mosses, thereby allowing the waters to discharge gently instead of running off at once. In connection with this, we may notice that the streams on the north-east side of the Snowdon range are gradually cutting their way back into the hills, thus shifting the watershed to the south-west of its general trend where these notches are formed. This is specially well seen in the case of the passes of Maes Cwm and Cwm Brwynog between Snowdon and Moel Eilio.

The literature dealing with the Snowdonian Lakes is not extensive. No doubt all geologists have read the masterly account of "The Old Glaciers of Switzerland and North Wales," by Professor Ramsay, which originally appeared in the series of "Peaks, Passes, and Glaciers," and was afterwards published separately in 1860. Recently Mr. W. W. Watts contributed "Notes on some Tarns near Snowdon," which will be found in the Report of the British Association for 1895 (p. 683) and also in this Magazine (Dec. IV, 1895, Vol. II, p. 565). During last Easter Vacation we paid some attention to the lakes and tarns of Snowdon, and believe that our observations may be of some use as a small contribution to the subject of the origin of lakes. In the first place we will deal with the lakes of the larger valleys of the Seiont, Gwrfai, and Gwynant, and then notice the lakes and lakelets which lie embosomed in the upland hollows of Snowdon.

The Seiont, rising at the Pass of Llanberis, flows in a north-westerly direction through the two lakes of Llanberis, Llyn Peris and Llyn Padarn. These lakes were once one, and are now separated by the alluvial strip near Dolbadarn Castle. This strip is part of the delta brought down by the stream which descends from the heights of Snowdon and Moel Eilio, and it is of interest to notice that at one time a considerable bay must have extended up the valley occupied by this stream, for alluvium extends some way towards the waterfall Ceunant Mawr. In Llyn Peris there is a bay on the south-west side of the lake, which is continued landward as a valley of some importance, down which a stream of minute proportions runs, and consequently the sediment which it has borne down has been insufficient to fill up the bay. Several similar bays at one time marked the south-west shores of Llyn Padarn, but as the lakes of Llanberis are now used as receptacles for slate-rubbish, the primary features of their shore-lines are almost obliterated. Llyn Peris once extended much further up the valley, as shown by the strip of alluvium extending to Gwastadnant.

The present exit of the river from Llyn Padarn is between two rocky masses, but there is a considerable width of ground, on which the bridge at Cwm-y-glo is built, which shows no rock *in sitú*, though it probably exists at no great depth beneath the surface. A depression occupied by alluvium leaves the lake on its western side, about a quarter of a mile south of the present exit, and curving round a rocky knoll joins the present stream opposite the village of Cwm-y-glo. It is somewhat over 100 yards wide in its narrowest part (where it

leaves the lake at the north end of the railway tunnel), and the alluvium is just above lake-level. There is no stream of any importance in this valley, and it is difficult to account for its existence unless we suppose that the main river ran through it, and that it became filled with drift, causing the formation of the lake, which drained over what was formerly a low col, situated at the present exit. Near the point where this old valley joins the present one, are several large pools in the present valley surrounded by alluvium. They are probably "kettle-holes" in the drift. The floor of the Seiont Valley is occupied by drift all the way from the lake to the sea, so that it is quite possible that the floor of the lake may be below sea-level and yet that the lake may not be in a rock-basin.

We now proceed to consider the two lakes of the Vale of Gwynant. Each is about three-quarters of a mile in length, and has its longer axis running in the direction of the valley. Llyn Gwynant is the higher of the two, and the bottom of the valley is occupied by drift between its foot and the head of Llyn-y-ddinas. At the head of the latter lake, the river has partly cut its valley through this drift, but without reaching the rock. The exit from this lake is apparently over rock, though no actual rock is seen in the stream at the outlet, but the width of the area devoid of rock is here very small. A bold rocky eminence lies between the foot of the lake and the road; the road is carried along a drift-filled depression west of the present exit for a short distance, and to the north of this the drift-filled depression is seen north of the road, and joins the lake a few hundred yards above the exit. This depression is about thirty yards wide in its narrowest part. To the south-west it joins the drift-covered bottom of the valley, and this valley-bottom is covered with drift to some distance below Beddgelert. It may be noted that Beddgelert stands on an alluvial flat which was once an old lake, and a barrier of rock runs across the stream at the entrance to the Pass of Aberglaslyn, but a drift-filled depression is seen to the west of this, which joins the main valley a short way down the pass.

The lakes in the Gwrfai Valley present points of some interest. Llyn Cwellyn is 464 feet above sea-level. An alluvial flat runs for half a mile from the foot of the lake, and no doubt marks a former portion of the lake filled up by the sediment brought down by the small streams from Moel Eilio and Mynydd Mawr. The water then runs over rock forming the cascade at Nant Mill, and the head of this cascade is only about five feet below the level of Cwellyn. At this point a barrier of rock extends right across the valley in such a way as to forbid the existence of any drift-filled depression, which could account for the lake. We lay special stress upon this point, for it might be urged that a possible drift-filled channel could be indicated in the case of all lakes, owing to the large extent of ground where live rock is not seen as compared with that which shows the rocks *in situ*. One of us has had considerable experience in the examination of the exits of lakes, and has found so many (like Llyn Peris and Llyn-y-ddinas) where there is only one possible exit, that he felt sure that if rock-basins exist with any frequency in

Britain, there must be some where proof is obtainable that there is no possible drift-filled exit. Cwellyn illustrates this: *there is no possible exit at the foot*, and if this lake were backed by high hills towards the head, the existence of a rock-basin could be proved here; but, as we shall now proceed to point out, the physiographical features at the *head* of the lake are compatible with the existence of a drift-filled depression in this direction; and, indeed, some of the phenomena exhibited above the head of Cwellyn are extremely difficult to explain, unless such a depression exists there.

An alluvial flat extends above Cwellyn for a quarter of a mile up the Gwrfai. This river runs over solid rock at Rhyd-ddu between Cwellyn and Llyn-y-gader, but a drift-filled depression is traceable from the head of the alluvial flat, firstly up the main stream, then up a tributary joining it a few yards south-east of Cwellyn Slate Quarry; it crosses a low watershed at a height of 740 feet (i.e., nearly 300 feet above the surface of Cwellyn, and nearly 150 feet higher than that of Llyn-y-gader), just east of Ffridd Slate Quarry, after which it follows another small stream and joins Llyn-y-gader close to the prominent crag, which stands out of the alluvium on the east side of the lake. This is the only possible exit in this direction, and its resemblance to a drift-filled gorge is very striking. The depth of Cwellyn is, so far as we are aware, not known; but assuming it is nearly 50 feet deep, the gorge, which is about 80 yards wide at the narrowest part, would require to be 350 feet deep at this point, in which case it would be comparable with some of the Alpine gorges. Such gorges might well be cut by the water issuing from a glacier, and highly charged with sediment, and the nature of the ground is favourable for the formation of one at this point, for it is occupied by a well-jointed basic intrusive rock. Furthermore, the rock comes to the surface here so extensively, that there is no approach to any similar drift-filled depression; in fact, where the depression crosses the col, it is a conspicuous feature owing to the rocky ridge above and below it, and it is difficult to understand why this continuous tract of drift-covered ground occurs here, except on the supposition that a valley lies below. If the possibility of the existence of the gorge be admitted, there is no difficulty connected with the introduction of the drift, for the locality is just beneath the great cwm on the west side of Snowdon, which must have been the gathering-ground of a large glacier, and also lies below the drift-covered tract on the upland plateau on which Maen Bras stands. There is another remarkable feature which requires explanation, but which is readily understood if it be supposed that a drift-filled valley exists here. To the south-east of Llyn-y-gader is a peaty moor, which slopes gently to the watershed separating the Gwrfai from the Colwyn. Viewed from the detached mass known as Pitt's Head, the watershed appears as a level line, and is apparently composed of an alluvial deposit. It strikingly resembles one which one of us has previously described at the head of Wet Sleddale in Westmoreland (Geol. Mag., Dec. IV, Vol. I, p. 539), and as in the case of the Wet Sleddale watershed, may be accounted for on the supposition that

a valley was here stopped up by ice, and partly converted into a lake, which became largely silted up with sublacustrine detritus. The bed of the Colwyn runs over drift until within a short distance of Beddgelert. It will be seen, therefore, that a continuous line of drift-covered tract can be traced from Nant Mill, past Cwellyn and Llyn-y-gader, for a distance of about four miles. If the drainage has been reversed between the present head of the Gwrfai and Nant Mill, the curious course of the stream from Llyn-y-dywarchen will be accounted for. This stream runs a little east of south into Llyn-y-gader, whilst the Gwrfai issues from that lake in a general northerly direction, whereas if the waters of the Cwellyn and Llyn-y-gader depression originally drained southwards, the Llyn-y-dywarchen stream would then have proved a normal tributary to the river once occupying that depression.

We may now pass on to the consideration of the upland tarns and lakes. The four tarns on the west side of Snowdon may be dismissed in a few words. The late Professor Ramsay speaks of them as follows: "The lake called Llyn Ffynnon-y-gwas is possibly dammed up by moraine matter"; and again, "a minor moraine encircles Llyn-y-nadroedd on the north and east, and another beautiful small one made of angular blocks and stones, now covered with vegetation, bounds Llyn-goch on the west and south-west, while a third dams up Llyn-glas." None of these lakes, then, can be claimed as resting in a rock-basin, nor can the drift-stopped tarn below Moel Eilio (Llyn Cwm Dwythwch) be asserted to rest in a basin of that nature. The lakes lying to the north-west of the main Snowdon ridge merit a fuller description. Below the precipice Clogwyn du'r Arddu, lies the little Llyn du'r Arddu at a height of 1,900 feet above the sea. The extensive moraine which blocks it up, and extends far down Cwm Brwynog in a series of concentric semicircles, is admirably described by Professor Ramsay. The exit to the west is between the great drift dam and solid rock; the latter is well rounded with striæ running parallel to the stream, and the rough sides of the *roches moutonnées* face westward. On them rest *sub-angular* perched blocks, whilst the innermost crescent of the drift-dam consists of *angular* blocks, as though some at least of this material was rather of the nature of snow-slope detritus than true moraine. It is quite clear that the course of the stream before the lake was formed cannot have been as it is now, otherwise no lake would have been produced; it must have run in a more northerly direction, but this former valley is now completely buried beneath gigantic moraine-mounds for a long distance. We call attention to this, as we shall have occasion to recur to the point when describing the exit of Llyn Llydaw.

The water of Llyn du'r Arddu is of a deep indigo tint, a colour not represented in Forel's scale of lake-colours. It is popularly asserted that the colour is due to the presence of copper in the water; but we are not aware that any analysis has been hitherto made to test this. Old copper-mines exist close to the lake, but as one of us has been unable to find any trace of copper in the lake-water, it would

seem that the colouring is not caused by the presence of this substance. The same may be said concerning the waters of Glaslyn and Llyn Llydaw, which have also yielded no trace of copper.

Cwm-glas is the next hollow which contains lakelets, and these have been specially noticed by Mr. Watts. He states that there can be little doubt that the upper lakelet "is a portion of a bending valley dammed at both ends by scree- and stream-débris, and thus compelled to find an escape over the rocky side"; and that in the rainy season the lakelet finds "a second outlet over the long, low col to the east, so that in this state it has the two outlets depicted in the six-inch map." We here find a missing link in the series of lakes leading up to those whose outlet is permanently over solid rock. One of us has described Hard Tarn on Helvellyn, a lakelet which strikingly recalls this tiny lakelet on Snowdon, being, like it, situated on a shelf formed by a dip slope between two escarpments (Quart. Journ. Geol. Soc., vol. lii, p. 13). In the Helvellyn pond, the normal outlet is over drift, whilst the wet-weather outlet is over solid rock; in the Cwm-glas pool, the normal outlet is over solid rock, and the wet-weather one over drift, for the drift has accumulated to a greater extent than that at the end of Hard Tarn. The next stage in the Cwm-glas pool will be the complete stoppage of the eastern exit over the drift, when the pool will drain permanently and in all weathers over the solid rock.

The lower pool of Cwm-glas is stated by Mr. Watts to be "certainly confined in a rock-basin, as rock occurs at its actual outlet, and at every point where any former outlet might have been possible. The lake is, however, so shallow that its occurrence in a basin of rock is perhaps of little consequence." We had hoped to obtain soundings of this lake, but owing to the quantity of floating ice, were unable to do so, although as the bottom is everywhere visible, there is probably no spot where the depth reaches six feet. We could not satisfy ourselves that the pool occupied a true rock-basin. The stream issues from the lake with a bank of solid rock at each side, but the stream is some feet in width here, and its floor strewn with boulders, and a former ravine six or more feet in depth might readily be blocked by detritus at this point. We do not, however, believe that this is the case, for just east of the present exit a drift-filled depression is seen, which runs parallel to the existing stream, and joins it about 150 yards below the exit, at a level far below that of the lakelet. The col in this drift-filled depression is about 15 yards north of the exit, and there we found a width of about five yards across from obviously live rock on either side. It is true that large blocks of stone here extend right across, but they do not seem to be *in sitû*, for the cleavage planes run in very different directions in the different blocks. It was easy to bury a walking-stick up to the handle at several points along this depression, and in other cases the stick was prevented from penetrating by coming in contact with obvious boulders which were movable. This pool, like the upper one, is situated on a dip slope shelf between two escarpments, and the ice

has merely rounded off the edges of the escarpments without altering their general character. It has acted like sandpaper, and there is no indication of such erosion as would produce a rock-basin,—quite the reverse. The same feature may be noticed in the case of Sprinkling Tarn on Scawfell.

The last cwm which contains lakes is the magnificent one east of the summit of Snowdon. The lowest lake, Llyn Teyrn, is shallow, and the stream from it flows over drift for a long distance below the exit. Near this tarn, and close to the path, a glaciated rock shows intercrossing striæ, one set running east and west and the other about 30° E. of N. and 30° W. of S. A better example of intercrossing is seen by the path bordering the shores of Llyn Llydaw, due west of the causeway. A *roche moutonnée* shows three sets of striations—one trending E. and W., another S.W. and N.E., and the third 35° W. of N. and E. of S. These directions point respectively to the top of Snowdon, the Lliwedd cliffs, and the cliffs immediately above the *roche moutonnée*, and were probably produced by glaciers coming from those directions at different times. We call attention to them to emphasize a difficulty which has often been felt if one assumes that glaciers can carve out rock-basins and yet are unable to obliterate the striæ formed at other times. Mr. Kendall has, however, shown that the same mass of ice produces intercrossing striæ; also, we are aware that glaciers, like rivers, must be under conditions more favourable for erosion at some times than at others; the difficulty is, therefore, by no means insuperable to those who maintain the power of ice to form rock-basins, but still we think it is a difficulty.

Mr. Watts writes:—"Immense quantities of moraine material occur on the south-east side of Llydaw, but a careful examination of the map shows that only two possible outlets exist—that now used for the purpose; and a second which is occupied by bog resting on moraine, and gives rise to a small stream which is joined lower down by the outlet of Llyn Teyrn. The moraine is, however, only a thin skin on the surface of the rock. The present outlet shows live rock forty or fifty feet below the level of the lake, and the second possible exit at a rather less distance below the same level. If the moraine were stripped off, there is little doubt that this lake . . . . would show a basin of rock which would hold water, unless it is very much shallower than is generally supposed to be the case." It is very desirable that accurate soundings of this lake should be made; indeed, we wish someone would do for the lakes of North Wales what Dr. Mill has so admirably performed in the case of those of English Lakeland. Mr. Watts' observations would permit the existence of a lake forty feet deep, which is not situated in a rock-basin, and our observations lead us to believe that a very much greater depth of water may be here held up by drift. A great moraine runs right across Llyn Llydaw near the present outlet. It is seen rising into high hillocks on the north side of the lake, projecting as islets from the lake itself, and covering much ground on the south side below the exit. No doubt it is, as Mr. Watts says,

a thin skin on the surface of the rock in many places. Rock, as he states, occurs in the stream which comes from the lake at a distance of forty or fifty feet below the exit, but the left bank of the stream is bounded by drift for a long way beneath this, and the stream is in places obviously cutting between drift and rock; nevertheless, we do not believe that the old exit was here. Viewed from above, a depression is seen running diagonally across the moraine-covered ground between the two streams mentioned by Mr. Watts, and this depression is marked by some pools, one of which is of sufficient size to be inserted upon the six-inch map. The depression joins the stream south-west of Llyn Teyrn, and the first live rock seen along this line occurs between Clogwyn Aderyn and Clogwyn Pen-llechen, south of Llyn Teyrn, at a vertical distance of nearly 200 feet below the level of Llyn Llydaw. The lesson taught by Llyn du'r Arddu proves that a buried valley need not show any marked traces upon the surface; and we believe that, even though the greater part of the moraine material forms a thin skin over the rock, a buried channel runs in an easterly direction along the route we have indicated.

The water of Llyn Llydaw is described by Professor Ramsay as being "of a green colour, like some of the lakes of Switzerland," though the difference of colour between the waters of Glaslyn and Llydaw did not appear to us to be very marked when we visited the lakes in the early spring.

Above Llydaw lies Glaslyn, at a height of 1,970 feet above the sea, and immediately below the great precipice surmounted by Y Wyddfa, the highest point of Snowdon. The tarn is very instructive. It is, as Mr. Watts remarks, "bounded on all sides by live rock, except at and near its outlet. This exit is over moraine, which, however, is not very deep, for rock makes its appearance just below, and in such a way as almost to compel belief in a complete rock-bar. Besides the present course of the effluent stream is a parallel strip of moraine running down towards Llyn Llydaw, but living rock soon makes its appearance in this." This parallel slip of moraine looks quite insignificant when viewed from the path; but when visited is found to be of considerable width. It joins the main stream at a vertical height of at least 50 feet below the exit, and at the junction a small stream is seen cutting its way backwards in the drift. Between the exit and the junction of this drift-filled depression with the present stream is a waterfall, and the water has here cut a *mere groove* in the rock. Moreover, we here meet with a most significant feature: *the bottom of the drift-filled depression is at a lower level than the present stream,* which runs at the side of the valley, being separated from the lowest part by a low shelf of rock. We here find a repetition of what one of us has previously noticed in the case of the tarn Smallwater, near Haweswater in Westmoreland (Quart. Journ. Geol. Soc., vol. xxi, p. 37), and we believe that the explanation given in that case is applicable to Glaslyn also. There is a feature of interest connected with the outline of the tarn. A bay occurs on the north side, whose shore-line forms a curve

parallel with those of the contour-lines above, where they run round a little valley occupied by a small stream. The existence of this bay is, of course, explicable if the lake be drift-dammed, but is difficult to explain if we suppose that it has been excavated by ice.

The colour of the water of Glaslyn is indigo, though the tint is not so deep as that of Llyn du'r Arddu. Here also copper-mines have been worked close to the lake, but, as has been mentioned above, no trace of copper was found in the water.

The samples, of which the analyses are appended in tabular form, were obtained under somewhat different conditions in the case of each lake. That from Llyn du'r Arddu was obtained from fairly deep water, surrounded on the landward side by rock *in situ*, that of Llydaw from the middle of the causeway which has been made across the lake, whilst that of Glaslyn was obtained from shallow water close to an ordinary foreshore, consisting of loose blocks and some vegetation.

	ARDDU.	LLYDAW.	GLASLYN.
	Parts per million.		
Solids { Inorganic	22	22	34
Solids { Organic	16	10	12
Hardness (Lime and magnesia salts) ...	22	20	22
Chlorine	9	9	12
Nitrogen as ammonia	·004	·094	·122
,, albuminoid ammonia	·026	·070	·048
Oxygen absorbed in 15 min.	·40	0	·40
,, ,, 4 hrs.	·40	·80	1·20
Nitrogen as nitrates and nitrites	·12	·16	·20

We did not think it necessary to determine the organic carbon and nitrogen, as the above results may be generally used as a substitute for them.

The analyses show that the waters of Arddu and Llydaw are similar in character: they contain about the same amount and variety of inorganic matter (chlorine, lime, etc.), but Llydaw contains rather more than twice the amount of organic matter that Arddu does, as shown by the albuminoid ammonia, and oxygen absorption in four hours. The similarity of the amount of chlorine also suggests that the organic matter is similar in the two cases. This result is what would be expected from the relative position of the lakes.

The results in the case of Glaslyn are very remarkable. The amount of solids (not lime and magnesia salts) and chlorine, also of ammonia (free and albuminoid), oxygen absorbed, and nitrogen as nitrates, would always be held to indicate the presence of much animal organic matter. This hypothesis seems at first ridiculous from the position of the lake, unless the hotel on Snowdon summit drains in any way into it. The only other interpretation is, that the sample obtained from near the bank was not of average quality. No impurity of such character could be introduced in any other way.

The object of these analyses, viz., to put to the proof M. Forel's hypothesis of the cause of coloration of mountain lakes, is unfortunately not attainable from these results, owing to the peculiarity

of Glaslyn, so that we must reserve this point for future work on other lakes, further from possible contamination.

In the meantime, failing an analysis of peat water of the above strength, there is some evidence in favour of the hypothesis from the cases of Arddu and Llydaw, though we were not able to match the indigo colour of these waters by means of his standard solutions. We failed to find any trace of copper. On a future occasion we hope to furnish more analyses.

In an article in *Science Progress*, new series, vol. i, p. 218 (1897), one of us describes some depressions formed on flat surfaces of rock in the Lake District, owing to the more rapid weathering beneath patches of moss, grass, and heather, which, when removed, leave little basins beneath them; and it was suggested that small lakelets might be produced in this way, especially in rocks which contained much soluble material. The depression in question occurred in the volcanic rocks of the Borrowdale Series. To show the effect of the weather upon rocks of this nature, a fragment of rock (possibly hardened mud with volcanic matter) was extracted from a peat-bog near Llyn du'r Arddu, and the analyses of the core and of the weathered crust are given side by side:—

	CORE.	CRUST.
SiO_2	79·20	72·00
Al_2O_3	16·74	22·36
FeO	1·96	2·55
Fe_2O_3	1·28	0·87
MnO	0·34	0·41
Alkalies	0·67	0·51
Loss on ignition ...	1·11	1·41
	101·30	100·11

III.—Note on the Life-Zones of the Carboniferous Deposits of Europe.

By Wheelton Hind, M.D., B.S. Lond., F.R.C.S., F.G.S.

IT has long been a matter of reproach to British geologists that, with such a grand sequence of Carboniferous rocks as occurs in Great Britain and Ireland, many of which are highly fossiliferous, all attempts to establish life-zones in them have hitherto been unsuccessful. As a subcommittee, appointed by the British Association, has been put into existence to endeavour to zone the Carboniferous rocks, it seems to me that a preliminary comparison with each other of the life-zones already established in Russia and Belgium, and as far as is possible to contrast the distribution of the zonal fossils with that which obtains in Great Britain, may to some extent clear the ground, and establish some important palæontological facts as a basis for future work.

Russian geologists are able to state without any hesitation that certain fossil forms are characteristic of certain zones in the Carboniferous rocks of Russia, and that these zones are, with very slight changes, the same for the Carboniferous deposits of Central Russia, the Ourals, and the Donetz basin. Three main stages are recognized

(with subdivisions and some small local variations), which are as follows:—

Upper Zone:

Spirifer fasiger, Productus cora, Spirifer supramosquensis, Conocardium Uralicum, Schwagerina princeps, Marginifera Uralica, with coal in the Donetz.

Middle Zone:

Spirifer Mosquensis.

Lower Zone:

Productus giganteus, P. striatus, Chonetes papilionacea, with coal-beds in Central Russia.

It is to be noted that in the Donetz basin the biological division between the upper and lower divisions is not absolute, *Spirifer Mosquensis* passing well up into the beds with *Productus cora*; but it would appear that *Spirifer fasiger*, Keys, does not trespass into the zone of *S. Mosquensis*, and the two fossils are never found together.

A large number of widely distributed Carboniferous species are common to all three divisions, but are not so frequent in the upper; and this, in addition, contains several forms which have never been noted in Western Europe, but which, on the other hand, are recognized as occurring in beds of the Salt Range period of India, and in the Carboniferous beds of North America.

Passing to the Carboniferous beds of Western Europe, De Koninck and Dupont are able to recognize three subdivisions in the calcareous deposits of Belgium:—

Stage III.—Upper—

Visean (detrital): Zone of *Productus giganteus, P. latissimus, P. striatus, P. cora, Chonetes papilionacea.*

Stage II.—Middle—

Waulsortian (corallian): *Amplexus coralloides, Syringothyris cuspidatus, Spirifer striatus, Conocardium Hibernicum.*

Stage I.—Lower—

Tournaisian (crinoidal): *Spirifer Tornacensis, S. cinctus, S. laminosus, Syringothyris distans, Athyris Royssii, A. lamellosa, Conocardium fusiforme,* etc.

This threefold division, however, is not accepted by all Belgian geologists. The Légende de la Carte géologique de la Belgique, dated 1896, shows only two main zones in the Carboniferous Limestone of Belgium—Visean and Tournaisian—the assise de Dinant, with *Chonetes papilionacea,* being considered as a facies of the Visean. The Waulsortian beds are placed as a facies of the Tournaisian, not typified, however, by any fossils; and the assise of Hastière, with *Spirifer Tornacensis, S. glaber,* and *Spiriferina octoplicata,* is considered to belong also to the lower group.

Gosselet ("Esquisse géol. du Nord de la France," 1880) proposes to divide the Carboniferous Limestone of France and Belgium into ten zones, but, judging from the lists of fossils given, probably not on palæontological grounds. He recognizes *Spirifer Mosquensis* as occurring at horizons below that of *Productus giganteus*.

It will be noted at once that the highest stage of the Carboniferous Limestone of Belgium is characterized by the same zonal form (*P. giganteus*) as that which is so typical of the lowest division in Russia, and that it is accompanied by *P. cora*, one of the zonal forms of the highest Russian division.

Although, some time ago, De Koninck was of opinion that *Spirifer Mosquensis* was found in the lowest Belgian (or Tournaisian) stage, in his paper "Sur le *Spirifer Mosquensis*" (Bull. Mus. Roy. d'Hist. Nat., tom. iii, 1883, p. 373) he showed that he had confounded this species with *Spirifer Tornacensis* and *S. cinctus*. In his remarks on the affinities of the latter shell, he states "qu'elle en diffère essentiellement [from *S. Mosquensis*] par sa grande taille, et, mieux encore, par l'absence dans sa valve ventrale des lamelles dentales divergentes, si fortement développées dans celle de sa congénère Russe."

In a later work, De Koninck figures *Spirifer spissus* from Stage III and *S. suavis* from Stage II, but these, judging from the drawings alone, I should not like to say were not varieties or specimens of *S. Mosquensis*; certainly they have much fewer ribs than the latter species.

I have lately attempted to solve the question whether *S. Mosquensis* really occurs in Great Britain or not. Originally Davidson figured two specimens in his Monograph on the British Carboniferous Brachiopoda (pl. iv, figs. 13 and 14) which agree very closely with Russian examples. Later on he was led to doubt the correctness of his determination through the influence of De Koninck's work. Unfortunately one of these figured specimens has disappeared, and probably only that one remains which is in the collection of the Royal Society of Dublin, but I have not been able to examine this example.

In the Appendix to the Monograph Davidson figures two shells from Scotland (pl. xxxiv, figs. 3 and 4) which closely resemble *S. Mosquensis* in shape, under the name *S. trigonalis* var. *bisulcata*. Dr. J. Young has kindly compared these shells with a typical Russian example, and says that the Scotch examples have much fewer ribs and that these are thicker.

I have, through the kindness of Professor Lloyd Morgan, examined the shell from the *Oracanthus* bed of the Lower Limestone shales of Clifton named *S. Mosquensis* by Stoddart, but this reference is an error, the shells having nothing in common.

I have also examined a fine series of shells labelled *S. Mosquensis*, from the Carboniferous Limestone of Co. Cork, in the collection of the Geological Survey of Ireland, I recognize amongst them *S. cinctus* and *S. Tornacensis* of De Koninck, but not *S. Mosquensis*. When placed side by side the differences between these three species are

very distinct, much more so than one would judge from the remarks and descriptions of De Koninck. Both *S. cinctus* and *S. Tornacensis* are more transverse, and possess fewer but thicker ribs, than *S. Mosquensis*. The construction of the dorsal mesial fold and corresponding sinus in the ventral valve is different in each species. At present, therefore, I am unable to affirm the presence of *S. Mosquensis* in Great Britain.

It is an important fact to note, in connection with the absence of the *Spirifer Mosquensis* zone in Belgium, that *Productus cora* and *P. giganteus*, the typical shells of the first and third zones in Russia, should occur together in Belgium, and that, according to the Belgian geologists, the beds with *Productus cora* are inferior to those with *P. giganteus*. In the *P. cora* zone of Russia the fauna, taken as a whole, is remarkably dissimilar to any that occurs in Western Europe, especially towards the upper portion, most of the species being entirely different.

The intimate study of De Koninck's later monographs cannot but convince the reader that with that author the erection of species was largely secondary to the knowledge of the horizons at which the various specimens were obtained. Starting with the preconceived notion that there were at least three distinct molluscan faunas in the Carboniferous Limestone of Belgium, he seized on the smallest differences in detail or growth as a reason to invent a new species, especially if it had been gathered from a special horizon. He says himself (Ann. Mus. Hist. Nat. Belge, sér. Pal., tom. vi, p. 4): "Si aux caractères différentiels constatés entre des spécimens provenant d'assises différents quelques faibles, qu'ils soient, vient s'ajouter une constance bien établie, il me semble loisible d'admettre que ces spécimens appartiennent à des espèces distinctes, et c'est ainsi que je les considererai." A very large number of the species which De Koninck states are confined to one or other of his three horizons in Belgium, I have found together in the Carboniferous beds of Great Britain and Ireland, and am inclined to think that many of his species will be found to be merely synonyms.

In the volumes on the Lamellibranchs of the Carboniferous Limestone of Belgium, 461 species are described by De Koninck, not one of which is said to occur except in one stage. The numbers are as follows:—

Étage Viséen	222	species
„ Waulsortien . . .	158	„
„ Tournaisien . . .	81	„
	461	

The species of Brachiopoda also are supposed to have had the same limited distribution, for not one of the 130 species described is common to two stages; and out of 499 species of Gasteropoda described only one species, and that with a query, is supposed to be present in two horizons. Thus De Koninck would have it that there are three absolutely distinct faunas, which never intermingle or

overlap. However correct these facts may ultimately be shown to be in Belgium, there is in the Carboniferous beds of Great Britain and Ireland nothing at all comparable to such exactness in the vertical distribution of the faunas of the Carboniferous period; and if one fact is emphasized more than another, it is that many species of Brachiopoda and Mollusca reappear again and again at various horizons, and survived throughout the whole of the epoch.

In Great Britain, *Productus giganteus* is a fossil very frequently met with, and of very wide vertical range. In the Pennine area it is met with in all the limestones from the Great Scar to the Crow Limestone, thus passing from the base of the Carboniferous Limestone to the top of the Yoredale Series. In Northumberland, it occurs with *P. cora* throughout the whole of the rocks grouped by the officers of the Geological Survey as the Carbonaceous division; and in Scotland is characteristic of the limestones of the Carboniferous Limestone Series, both upper, middle, and lower divisions. In North Wales, *P. giganteus* passes from the Middle White Limestone of Mr. Morton to the top of the series, accompanied in the Middle White and Upper Grey Limestones by *P. cora*, which shell is found alone in the lowest member (the Lower Brown Limestone) of the series. In South Wales, Mr. Morton finds *P. giganteus* and *P. cora* in the limestones of Gower, and Mr. Stoddart records both these fossils in the Carboniferous Limestone of the Bristol district. Mr. Stoddart published (Proc. Bristol Nat. Soc., new ser., vol. i, 1874–6, p. 318) a very careful account of the various beds of the Lower Carboniferous Shales and Carboniferous Limestone of the Bristol Coalfield, and the fossils contained in them. The majority of the Mollusca and Brachiopoda are not, however, zonal forms, but are found at various horizons in the Carboniferous series, both there and elsewhere. M. Max Lohest, after going over the ground, published a small pamphlet entitled "Sur le parallélisme entre le Calcaire Carbonifère des environs de Bristol et celui de la Belgique" (Ann. Soc. Géol. Belge, tom. xxii, p. 7), in which he would establish an almost complete identity between the Bristol and Belgian series. This author recognizes zones indicated by A, B, D, E, F.

A. Beds with *Modiola Macadamii* and *Avicula Damnoniensis*, which correspond with those of Comblain au Pont. Mr. Stoddart, however, pointed out the close connection of the fauna of these beds with that contained in the Marwood, Coomhola, and Moyola beds.

B. This bed is a red crinoidal bed, with *Spirifer glaber*, *S. bisulcatus* (?), *S. Tornacensis*, and *Spiriferina octoplicata*, identified with the lower part of the Tournaisian beds of Belgium; but, with the exception perhaps of *Spirifer Tornacensis*, all the other fossils are found in the zone of *Productus giganteus*, if not near Bristol, in the topmost beds of the Carboniferous Limestone of Derbyshire and Yorkshire. M. Lohest says: "Le base du terme B paraît bien être l'équivalent de notre assise à *Spirifer glaber*; les schistes du sommet représentant nos schistes à *Spiriferina octoplicata*"; but in Great Britain both these forms are most abundant in the upper part of the Carboniferous Limestone.

D is a bed of crinoidal limestone.

E is a bed of dolomitic crinoidal limestone.

F is a thick oolitic limestone, which is considered to correspond with the base of the Viséan, with *Productus cora* in the lower part and *P. giganteus* above.

In this succession, Dupont's Waulsortian division of Belgian rocks is entirely absent, and the chief features on which the identification of the two series of beds is based are purely petrological, and not palæontological. There are so many horizons at which beds of crinoids occur, that unless species can be recognized, such statements are utterly valueless for the purposes of identifying horizons.

The Avon section shows the following sequence:—

Zone of *Productus cora* and *P. giganteus*	Mountain Limestone, 2,000 feet.
Productus giganteus and *P. cora* absent	Lower Limestone Shales, 500 feet.

In a paper published in the Annales du Soc. géol. de Belge, tom. ix, 1881–2, p. 31, De Koninck, describing some new Cephalopoda from the Carboniferous Limestone of Ireland, gives three lists of fossils which he considers as typical of the three series of beds established in Belgium by Dupont, and states that he is able to make out the same three zones in Ireland from the study of specimens in various museums and collections. He considers that the following parallels occur:—

Ireland.	Belgium.
1. Limestone of Armagh.	Calcaire des Ecaussènes et de Comblain au Pont.
2. Calcareous schist of Hook Point.	Calcaire de Tournai.
3. Limestones of Rathkeale and Co. Limerick.	Calcaire de Waulsort.
4. Limestones of Cork, Dublin, Galway, and Meath.	Calcaire de Visé.

If a comparison be made between the lists of Carboniferous fossils from these districts which were drawn up by the late Mr. Baily for the Memoirs of the Irish Geological Survey, it will be seen at once that no such palæontological divisions can be shown for the Irish Carboniferous beds. Indeed, most of the species on which De Koninck relies for the identification of his three life-zones are not confined to the horizons which he mentions. For example, *Zaphrentis cylindrica*, *Syringothyris distans*, *Spirifer laminosus*, *Athyris Royssii*, *A. lamellosa*, and *Orthis Michelini* are said to be characteristic of the Tournaisian; but in Great Britain and Ireland these shells are found to have survived all through the deposition of the limestones, being not at all rare in the upper beds. The fossils of the middle zone are equally associated with those of the upper and lower in British localities, while *Productus giganteus* and *P. cora* are by no means confined to the upper beds. For example, *P. giganteus* occurs at Hook Point in the Lower Limestones with *Syringothyris cuspidatus*,

Spirifer striatus, S. laminosus, Orthis Michelini, Conocardium fusiforme, Athyris Royssii, and *Amplexus corolloides.* At Armagh, *Productus giganteus* occurs at twenty-five different localities, at one of which it is known to occur with *Orthis Michelini, Spirifer laminosus,* and *Zaphrentis cylindrica* ; in fact, unfortunately for De Koninck's rapid generalizations, *Productus giganteus* occurs in all the Carboniferous districts of Ireland, and seems to have survived from the deposition of the Lower to that of the Upper Limestones. Although copious lists of fossils and localities are accurately given in most of the Memoirs of the Geological Survey of Ireland, it is a great pity that those who had to produce them did not see fit to arrange the lists of fossils according to the horizons, instead of only giving localities, and leaving it to the student to identify the horizon of each locality by a reference to the colour which is shown on the map at each place. In the Memoirs of the Scotch Survey, and the later English one, the reader is able to see at a glance not only the locality, but the actual horizon whence each fossil was obtained.

It would therefore appear that in Great Britain the zone of *Productus giganteus* is very largely developed. In the Southern Pennine district this fossil characterizes the beds from the base of the Lower Scar Limestone to the Upper Limestone (the Crow) of the Yoredale group. In Scotland, however, and, to some extent only, in the Pennine and Bristol areas, this extensive zone is preceded by a series of rocks in which this fossil is absolutely wanting—the Calciferous Sandstone Series, which are probably represented only by the basement beds of the Ingleboro area and the Roman Fell beds further north. It is difficult to suggest a zonal form for this series, much of which is non-marine; but on the Fifeshire coast *Sanguinolites Abdensis,* Etheridge, and *Schizodus Pentlandicus,* Rhind, seem to be confined to the series; and *Modiola Macadamii* is characteristic of the Lower Limestone Shales of Bristol and the Coomhola and Moyola beds of Ireland.

The shales overlying the limestones in Derbyshire and Yorkshire, I have shown to contain a fauna totally distinct from the Carboniferous Limestone and the Yoredale beds of Wensleydale (Geol. Mag., 1897, Dec. IV, Vol. IV, pp. 159–169 and 205–213). This series, mapped by the officers of the Survey as Yoredale beds, may be described as the zone of *Aviculopecten papyraceus, Gastrioceras carbonarium, Posidoniella minor,* and *P. lævis,* and includes the Lower Coal-measures or Ganister Series, Millstone-grits, and shales below them; while the Coal-measures may well be subdivided into the upper, or zone of *Anthracomya Phillipsii,* and lower, or zone of *Naiadites modiolaris,* with many local horizons at which only certain fossils have as yet been known to occur.

The following table gives the equivalents of these zones in England, Scotland, and Ireland, from above downwards :—

	England.	Scotland.	Ireland.
1. Zone of *Anthracomya Phillipsii*.	Upper Coal-measures of Lancashire, Yorkshire, Staffordshire, Bristol, including the *Spirorbis* Limestones.	The Red Beds of Fifeshire.	? Wanting.
2. Zone of *Naiadites modiolaris* and *Anthracomya modiolaris*.	Middle Coal-measures universally.	The Red Beds of Fifeshire.	Coal-measures.
3. Zone of *Aviculopecten papyraceus*. *Gastrioceras carbonarium*, *Posidoniella lævis*, and *P. minor*.	Ganister Series. Millstone Grit. Shales below the Millstone Grit universally.	? Wanting. Note.—*Aviculopecten papyraceus* is said to be found some distance above the Ell Coal in the Wishaw district, Lanarkshire; but I have never seen this fossil in any Scotch collection, and the determination is possibly erroneous.	Castlecomer, Leinster Coalfield. Coal-measures of Fynes, co. Limerick.
4. Zone of *Productus giganteus* and *Productus cora*.	The Carboniferous Limestone of Derbyshire. The measures from the Great Scar to the Main Limestone, N. Yorkshire. The Carbonaceous Division of Northumberland. Carboniferous Limestone of Wales and the Mendips.	The Carboniferous Limestone Series of Scotland { Upper, Middle, Lower.	The Upper Limestone. The Calp. The Lower Limestone.
5. Zone of *Modiola Macadamii*.	The Lower Limestone Shales of the Mendips and South Wales, with several fossils common to the Old Red Sandstone Series and the Carboniferous.	The Calciferous Sandstone Series, with *Schizodus Pentlandicus* and *Sanguinolites Abdensis* in Fifeshire, and a fauna very different from the English and Irish equivalents. Mr. Kirkby states that *Productus cora* is contained in the upper 500 feet of these beds.	The Coomhola and Moyola beds, forming a passage from the Old Red to the Carboniferous, and containing certain fossils common to both.

Series 1–3 constitute what I consider to be the "Upper Carboniferous," and series 4 and 5 the "Lower Carboniferous," of my paper on the Yoredale Series (Geol. Mag., April and May, 1897).

While the zone of *Productus giganteus* corresponds to the Viséen of Belgium, the lower zones of Great Britain do not resemble the

Waulsortian or Tournaisian in their faunas. My own view, from a comparison of the Belgian and British fossils, is that the zone of *P. giganteus* in Great Britain and Ireland corresponds to the whole of the Belgian series; for none of the fossils which are relied upon by MM. De Koninck and Lohest to identify the lower beds in both areas are in Great Britain and Ireland confined to the Lower Limestone Shales, but are found in abundance, and in a full condition of growth, at the top of the zone of *P. giganteus*.

The faunas contained in the beds of shale differ markedly from those contained in limestones, the shales being much richer in Lamellibranchs and Crustaceans, and comparatively poor in Brachiopods and the Actinozoa. Consequently the faunas of the same zone, taken as a whole, vary very much according to locality and the nature of the sediment. Consequently the zone of *P. giganteus* in Scotland, in which the limestones are separated by thick beds of shale, contains a very different fauna from that which obtains in the same zone in Derbyshire, where the shales are practically absent, and the limestone exists in one mass, made up of beds of various lithological characters.

IV.—The Contact-Rocks of the Great Whin Sill.

By W. Maynard Hutchings, F.G.S.

IN what follows, it is proposed to give a general description of the effects of contact-metamorphism, observed in the rocks altered by the intrusion of the Great Whin Sill in Durham and Northumberland.

The work, of which this is the condensed result, has been carried on for the last four years in the microscopical, and to some extent chemical, study of a large series of specimens collected at many points along the course of the Whin Sill exposure by Mr. E. J. Garwood, and also, to a very much smaller extent, by myself. Mr. Garwood has been for a long time engaged in a detailed examination of the geology of the district, and will in due course publish the results of his work, which is not yet complete. It was at his suggestion and request that I undertook the petrological study of the specimens collected.

As is well known, the rocks into which the Whin Sill mass has been intruded consist mainly of limestones, shales, and sandstones of the Lower Carboniferous beds. The special interest and value of the contact-effects here displayed, are enhanced by the fact that the rocks acted upon were all in what may be called a perfectly simple and elementary state. We know exactly what they were like before they were altered by the intrusion, and can study them as fully as we wish, in their original and normal condition, in the same and other districts. Thus, the shales, the metamorphism of which gives us the most interesting portion of the material, with the most important bearings upon the question of contact-action in general, are in all respects counterparts of those from the Coal-measures and the Lower Carboniferous, which I have described in

full detail in previous papers in this Magazine. None of the rocks affected had undergone any sort of "development" previous to the intrusion of the Whin; and as they have not been in any way changed, except by weathering, since the consolidation and cooling of the igneous mass, we are able to see with considerable certainty just what mineralogical and structural changes are to be ascribed to contact-metamorphism.

Such comparatively simple and reliable conditions, in a contact-area of such importance, are so very rare that it is at once apparent how valuable are the indications we may derive from them, and how great is the assistance they may render to us in our endeavours to understand the much more complex cases usually presented to us. I say "in a contact-area of such importance" because, as I shall show, we have here exactly reproduced for us a large portion of the phenomena we are accustomed to see round the intrusions, on a much mightier scale, of granite, etc. It makes no difference that in greater contact-areas the mineralogical and structural details are more striking as to size, so long as on the smaller scale they are equally clear and distinct.

I propose to deal with the altered rocks in the following order: pure or almost pure limestones, argillaceous limestones, shales, calcareous shales, sandstones. These, however, pass over into one another in all degrees, and there is, of course, no sharp division between limestones, argillaceous limestones, calcareous shales, shales, quartzy shales, argillaceous sandstones, and sandstones or grits. It is among some of the intermediate rocks that the most interesting effects are produced.

When a sufficiently large number of specimens had been sliced and examined, it became evident that there was no use in multiplying them beyond a certain point. It was clear that the same results of alteration could be found at intervals all over the long course of the Whin Sill, wherever the chemical nature of the invaded rocks was the same. For this reason, in the following descriptions, particular localities of occurrence will only be mentioned when specially interesting or pronounced developments have taken place, which are qualified to serve as good types of the alterations in general.

Commencing, then, with the limestones, we find that when these are pure, or at all events are non-argillaceous, the action of the Whin Sill upon them has been limited to a recrystallization of them. In some cases this recrystallization is very finely marked, and may stand alongside of the "marmorization" of similarly pure limestones by intrusions of granite.

Whether interfusion has taken place to any extent between the Whin and the purer limestones, at some points, is a question which it is not possible to answer decisively. In many actual contact-slides examined there does not seem to be evidence that any such action has occurred at all; the division line is quite sharp and clear, the Whin is small-grained but quite crystalline right up to the junction, and the recrystallized limestone begins equally sharply on

the other side of it. If there be recrystallized quartz, this also often comes quite sharply up to the contact-line.

In some instances there does appear to be a very narrow streak of more indefinite matter, possibly denoting interfusion; and there are other cases where a very noticeable band is seen of what has clearly been of a tachylitic nature; though whether we ought to regard it as a true tachylite,—i.e. a product simply of rapid cooling of the edge of the molten igneous rock,—or whether it is more a result of interfusion, I think cannot be settled, because chemical analysis would not here give a sufficiently definite answer. So far as microscopical evidence can help us, I rather incline to the view that it points to interfusion having taken place to some extent. Thus, the most striking example is one from Middleton Wood, near Belford. In the hand-specimen the tachylitic material was some two inches thick, and in the slide prepared from it, over the line of contact, there is nearly half an inch of it. The limestone is simply crystallized, as is also silica which it contained. It has not had any new minerals formed in it, but *quite close* to the junction there are a few colourless garnets, just a narrow string of small crystals and grains. Then comes the tachylitic band, mainly a yellow to red-brown glass, with a good deal of indefinite, speckly, felsitic-looking matter, and chloritic decomposition products, but with some felspars and augites of good size dispersed in it, and a few prisms of enstatite. With these is also a good deal of garnet in small grains, and at some parts patches of it of much larger size. As no garnet occurs in the altered limestone except at the actual contact, and as it occurs in the tachylitic band, it seems likely to be a product of the interaction of limestone and Whin. No garnets seem ever to occur in the normal Whin Sill rock.

In some other specimens examined there is, again, a narrow band of what appears to be another product of such interaction. There is a seam of what appears to have been tachylitic, now very much obscured by calcite and chlorite due to decomposition. The limestone is perfectly free from any new mineral formation. But on the side towards the Whin comes a zone of close-grained igneous rock, a narrow strip of which is coloured brownish-red of a peculiar shade. Under higher powers it can be made out that this reddish band contains swarms of minute flakes of mica, and that it is from these that it derives its colour. Here and there the compact swarms of this mica open out, and become more scattered and larger in size, some individuals being seen as fairly well-bounded crystals, which can be recognized as a deep brown-red very dichroic biotite, some of the best flakes giving a good optic figure in convergent light with $\frac{1}{12}$ inch objective. None of this mica is ever seen in the normal Whin, and I have not seen any signs of it except at contacts with pure limestones. It certainly appears to be an endomorphic formation in the igneous rock, brought about by interaction with the limestone, though it does not seem easy to explain the chemical reactions which have been concerned in it. I do not recollect any mention of a similar result on an intruded igneous rock, and have certainly never seen it myself in any other case.

We will now pass on to the altered argillaceous limestones, including under that head all such rocks as are still safely to be recognized, microscopically and chemically, as having been dominantly limestones, but which have contained sufficient shaly material to provide a noticeable amount of silica and alumina, with some alkali and magnesia, which latter will also be present, more or less, in any case, in most of the limestones. Rocks of this class, of varying degrees of admixture, occur at many points along the Whin Sill, and have given rise to very interesting contact-products. The new minerals formed are garnet, augite, idocrase, wollastonite, epidote, hornblende, felspar, chlorite, sphene. The garnet is the most persistent, being seen in all the slides examined from rocks of this class, whereas most of the above minerals may be present in some cases and absent in others.

One or two typical examples will serve to give a general idea of the nature of the alterations produced. Thus, from specimens of not very impure limestones from Burtreeford, sections have been cut which show the actual contact-line. First comes a narrow band (about $\frac{1}{30}$ inch) which seems to mark some sort of interfusion. Though now much obscured by fine-grained secondary calcite, it is distinctly defined both on the side towards the Whin and on that towards the limestone. The Whin is very fine-grained, but contains a good many perfectly fresh and distinct crystals of felspar of larger size. Occasionally one of these crystals projects just into the edge of the interfusion-band, and may be seen to have been melted away in it and left with a rounded end.

Along the edge of the band towards the limestone lie many small but good crystals, and some irregular grains, of idocrase. The largest crystal in these particular slides is a prism $\frac{1}{60}$ inch long by $\frac{1}{130}$ inch wide, very fresh and perfect. A very few lie also a little further in, but none occur at any distance from the contact-line. It is interesting to note the mode of occurrence of these crystals, some of which are completely bedded in quartz, some again in calcite, and others in grains of calcite which are surrounded by quartz.

Then comes another narrow zone, about $\frac{1}{160}$ inch, which consists largely of recrystallized quartz as a sort of ill-defined mosaic, intermixed with varying amounts of calcite. This quartz is all full of inclusions of small garnet grains and indeterminable microlites, and clearly dates from the original metamorphism of the limestone by the intruded Whin, being strongly distinguished from later quartz which has filled in small cracks, etc., and which contains no such enclosures. This quartz band passes abruptly into coarse-grained, highly crystalline, saccharoid limestone, the calcite crystals containing numerous small garnets in rounded grains. A deep-coloured, very dichroic sphene, in good-sized crystals and grains, is also present.

Rather more impure limestones are represented by specimens from Rumbling Churn, near Dunstanburgh. Garnet is again very abundant, mainly in very small crystals and rounded grains

averaging about $\frac{1}{1000}$ inch in diameter, but in some cases reaching $\frac{1}{100}$ inch and a little over.

At some parts of the slides these garnets are packed so close that scarcely anything else is visible. They vary from colourless to yellow and greenish, and some are a rich red-brown. Often the centre is coloured, and the outer rim is colourless. Augite occurs plentifully with the garnet, in good-sized crystals and large irregular complex grains. It is all perfectly fresh, and some of it is of a very decided green colour, and slightly dichroic. Both garnets and augite come right up to the contact-line, and in one slide may be seen lines of very small augite crystals, clearly of contact-origin, growing out from the edge of the Whin, like the teeth of a saw, into the limestone. A very pale hornblende in slender needles is also present at some parts; epidote and sphene are well represented, and there is a good deal of recrystallized quartz, which frequently encloses garnet and augite. The remaining calcite of the limestone is completely recrystallized. There are often large fields of one uniform grain of it, with numerous garnets and augites contained in it.

In the mosaic of recrystallized quartz in these highly calcareous rocks one may often suspect felspar to be present, but without being able to make sure of it, owing to absence of cleavages and the impossibility of making reliable optical tests. In one specimen from near Dunstanburgh, however, an altered limestone shows numerous small crystals, together with more or less irregular grains, of well-cleaved fully-individualized felspar. Some few of the crystals even allow of identification, with much safety, as anorthite or a closely-allied species (sections with parallel cleavage, extinctions 30°–40°, with emergence of good axial bar inside the field). They lie in amongst very coarse-grained recrystallized calcite, near the junction with the Whin. It will be seen later on that some of the altered shales contain abundant new felspar. The above specimen shows also a few garnets, some epidote, a good amount of recrystallized quartz, together with a considerable amount of wollastonite, mainly in tufts and bunches of often sheaf-like, radiating fibres, with here and there bits of sufficient size for the application of optic tests. This mineral appears to be not of frequent occurrence in these rocks. Indeed, it may be noted that, so far as concerns the limestones which are reasonably free from any admixture except silica, there seems seldom to be any reaction between the lime and the silica. Calcite and quartz recrystallize side by side, and it is rare to see in these particular rocks any formation of wollastonite, or of any calcareous hornfels-like products, such as are more frequently encountered round granite-contacts.

Sometimes there were little bands of sandstone in the pure limestone, quite close to the contact. A specimen from near the Roman station of Borgovicus, close to the Whin, is sliced so as to show both recrystallized limestone, very saccharoidal, and sandstone converted into a well-cemented quartzite, with some new felspar among the interstitial matter. The division-line of the two products is very clear and sharp, and there has not been a trace of action between them.

It is not only close to contact that these limestones have been affected. Complete recrystallization is seen at more than 60 feet away, and small augite crystals are seen in a specimen over 40 feet distant.

We may now turn to the consideration of the alteration-products of the shales. These shales along the contact-area of the Whin Sill have varied in nature in every degree, from argillaceous beds almost quite free from quartz, to others in which that mineral has formed a large proportion. For our present purpose we will call them all shales, speaking of them as more or less sandy, and only draw the line where the quartz has increased so largely that we must recognize them as argillaceous sandstones and classify them accordingly. Of this class of rock a very large number of specimens have been examined, but here again a few examples will suffice to give a clear idea of the general lines on which the metamorphism has proceeded. The intensity, and to some extent also the character, of the alteration varies more or less at different places. This is partly due to different composition, notably the variation in the amounts of quartz and of alkalies contained affecting the susceptibility of the beds to contact-action. Partly it is due also to the varying bulk of the intruded rock at different points, and sometimes we cannot account for the variation except by assuming some difference in the local conditions of the invaded beds, as to temperature, degree of hydration, etc., before the intrusion occurred.

Outwardly the change undergone by the originally soft shales consists in great induration, accompanied by more or less lightening of colour. In the inner zones of action, nearer the igneous rock, (sometimes also at considerable distances), the soft, fissile, dark-coloured shale has been altered into a hard, compact, grey or greenish-grey rock, with often very little fissility remaining, and in many cases completely replaced by a conchoidal or almost flinty fracture.

Inwardly, as revealed in thin sections, the most constant and striking change lies in the production of new mica, with chlorite, with a totally new structure as well as new mineralogical composition. Newly crystallized quartz is also frequently a main feature, in some cases felspar has been abundantly produced, and we have examples of the appearance of special contact-minerals in the form of biotite, andalusite, anthophyllite, etc.

If we take first the purest shales, which have had little, if any, quartz, and which have a chemical composition like that of some of the purest "fireclays," we find that where the contact-action has been most intense we have a complete recrystallization of the entire rock, with formation of a new mass of white mica throughout. Instead of the minute flakes of the indefinite micaceous mineral which has been produced in the fireclay or shale, making its main constituent, and lying nearly all in one plane, we get a network of much larger, well-developed flakes and crystals of white mica, lying criss-cross in all directions. In many cases a good deal of it is grouped together in fans and sheaves, and roughly spherulitic

aggregates giving more or less black-cross figures in polarized light. Intimately mixed and interwoven with this new mica is an abundant chloritic mineral. This chlorite forms part of the sheaves and spherulitic groups, and all over the slides is seen to have been formed flake for flake *with* the mica, as a result of one and the same process. No such chlorite exists in the unaltered beds; as I have previously pointed out, both it and the white mica are the result of a splitting-up and higher development of the impure and complex micaceous mineral of the clays and shales. In some cases there is a certain amount of biotite formed, with a similar mode of occurrence, but this is not frequent among these rocks. The formation of "spots" may also be seen on a copious scale in some specimens; and these spots, though small, are exactly analogous to the larger ones seen at some granite contacts, being due to the aggregation of the chloritic material which is separated out during the recrystallization of the rock constituents.

One or two special examples of the alteration of these pure shales may be given in illustration. Thus, a specimen from Rowntree Beck, taken 18 feet below the Whin, is very highly altered but still contains good fossils. An analysis of it gives—

Silica	51·40	per cent.	
Alumina	26·85	,,	
Ferric Oxide[1]	6·15	,,	
Lime	0·56	,,	
Magnesia	2·38	,,	
Potash	5·21	,,	} 6·99
Soda	1·78	,,	}
Water	6·45	,,	
	100·78		

This composition shows the rock to have been originally of the nature of a fireclay, closely resembling some of the series of which I published analyses in a former paper (GEOL. MAG., 1894, Dec. IV, Vol. I, pp. 36–45 and 64–75). It is now a muscovite-chlorite rock, with abundant "spots" all over it. Into these spots is concentrated nearly all the pigmental matter of the rock, together with chlorite and numerous dark grains and microlites, so that the spots are dark in a light field. Parts of this field are almost clear and colourless. In polarized light they are seen to consist of an interlacing mass of muscovite and pale chlorite. Sheaves and spherulitic bundles of mica and chlorite abound all over the section, and there is no sign of any definite orientation of these minerals in any direction. The entire rock is crowded with small grains and crystals of rutile recrystallized from the original "needles" of the shale.

Another interesting spot-rock comes from near High Force. In ordinary light a section of it shows a sort of marking off into roughly polygonal, or approximately circular, clear spots, framed in

[1] In this and following analyses *all* the iron is reported as ferric oxide, no special determination having been made of the portion which is always present as ferrous oxide. This often causes more or less excess in the totals, but is not of any importance for the purposes for which these analyses were made.

darker greyish and brownish pigmental matter. The spots are mostly of a very pale greenish colour, and proper illumination enables us to see countless flakes and crystals of a chloritic mineral. With crossed nicols the whole slide is resolved into a network of muscovite flakes, lying again in every possible direction, and amid the brightly polarizing mass of this mica the chloritic spots are more or less dark and isotropic. In some the transition from the bright frame of mica is quite sharp ; in others mica projects more or less into the spot, and only the centre is free. Many spots show a field of quite isotropic, pale-green substance, in among which a dim and speckly fine-grained mosaic polarization is discernible. These spots are again in all respects exact counterparts of what may be seen at some granite-contacts. It is curious to observe that, whereas in the previous example the dark pigmental matter has concentrated inside the chloritic spots, in the present case it has remained completely outside them, and is mixed in with the mica. I have made no analysis of this rock, but it shows only a very small amount of recrystallized quartz, and is no doubt very closely the same in composition as the last. No trace of clastic muscovite remains in either of these, and, indeed, in nearly all the highly altered fine-grained shales examined, it has absolutely disappeared and entered into the same complete recrystallization which has affected the main mass of secondary micaceous and other material of which the shales and clays were composed.

Perhaps among these very fine shales examined, the most interesting case is shown in a specimen from near Winch's Bridge, in Teesdale. It is from a body of rock which has been caught up by the Whin. It contains—

Potash	5·71 per cent.	} 7·20	
Soda	1·49 ,,		
Water	7·40 ,,		

This is very nearly the maximum of alkali which I have found in any of the carboniferous shales and clays. It can have contained but little quartz. When it is examined under the microscope it is seen to consist, to a very large extent, of the peculiar substance which I have previously described in detail as being found in varying quantity in so many altered rocks around granites (Geol. Mag., January and February, 1894). I traced and described its various modifications and developments, and endeavoured to show the probable nature of its origin and the part it plays in the changes going on during contact-metamorphism. There seems every reason to regard it as a product of the *solution*, or "aqueous fusion," of original materials preliminary to recrystallization. Sometimes we see it in a quite amorphous state. Its first stage of development from this shows a faint minutely-speckly polarization. At very thin edges, with high powers and suitable illumination, it is seen to be very finely granular. We can see it in contact-slates in all stages of evolution, from the first appearance in it of very few and small mica-flakes, up to a full development of new mica out of it.

I alluded, in the paper referred to, to the fact that this substance could be seen in the contact-rocks of basic intrusions, but in less amounts than at granite-contacts. I had not at that time seen the specimen we are now considering, which shows the substance in greater amount than any other I have ever seen, and which strikingly confirms the view at which I had arrived concerning its origin and nature. It here forms a sort of base, or groundmass, all over the slide, and is nearly colourless, there being very little iron present. None of it is quite amorphous, but it has the speckly minutely felsitic polarization. Mica has formed in it throughout, but not regularly diffused, so that whilst at some parts there are patches, large enough to fill the field of a half-inch objective, in which but a few small distinct flakes are to be seen, we have other portions made up so entirely of mica that little of the base-substance can be seen among it. We can trace the growth of the mica in all stages. It is to a large extent in tufts and sheaves and rosettes; many of these of all sizes, as well as single flakes and crystals, and crossed and interlaced groups of them, may be seen brilliantly polarizing, floating free, as it were, in the nearly amorphous material out of which they have grown.

It is quite clear that what we here see is an intermediate stage,—an interrupted development,—on the road towards some such final product as the two examples we have just been studying. Had the conditions suitable for the crystallization of the mica continued long enough, we should have had a complete and uniform development of that mineral, together with its attendant chlorite, as before. But it is just the fact that the conditions did *not* continue long enough for completion of the process, which gives such particular interest and value to this occurrence. Such interrupted cases, when we can get them, are capable of teaching us more of what actually "goes on" in these contact-metamorphisms than any number of completed examples, where often all trace is lost of the steps by which the final result has been arrived at.

The rutile of the altered shale has crystallized out in much larger and more definite crystals than the original needles, many of them as "hearts" and "kites," and the entire slide, mica as well as base-substance, swarms with them. A good proportion of the mica, in this case, is brown and strongly dichroic, especially some of its larger tufts and sheaves. There is no clastic quartz remaining; what little there was evidently entered into the general process of solution, and has reappeared as newly-formed mineral. It is also interesting to notice how the numerous small zircons of the original shale have resisted, as they so frequently do, the solution which has destroyed all trace of everything else, and how they remain quite unaltered among the new products.

The greater number of shales affected by the Whin Sill have not, however, been as purely argillaceous as the above examples. They have mainly been more or less sandy. But their alteration has proceeded on much the same lines as those described, and it will not be necessary to consider them in much detail. In some of the more

highly metamorphosed beds all original quartz has disappeared, and has been replaced by newly-formed contact-quartz. Where the amount of it is sufficient, we sometimes get a good "mosaic" of the same nature as what we see so universally at granite-contacts. Where there is less of it, we see it disseminated among the micaceous part of the rock in single grains, and groups of grains. In less intensely affected cases we get more or less clastic quartz remaining; sometimes it does not seem to have been attacked at all, and again, we may be able to see various degrees of its attack and corrosion by the processes of solution which took place. With the more or less regenerated quartz we nearly always see that the argillaceous position of the shale has given rise to just the same products as those we have been considering, the mica and chlorite, the spots, and the residual speckly substance, all appearing in the same relationships as to individual forms and general structures.

Among these altered sandy shales, however, there are some occurrences which are of such special interest that they must be here alluded to, in connection with the review of the whole contact-phenomena of the Whin Sill and their bearings on the general question of contact-metamorphism. In a former paper ("An Interesting Contact-Rock," Geol. Mag., March and April, 1895) I gave minute descriptions of the rocks to which I allude, and I would refer students of the subject to that paper, limiting myself here to a recapitulation of the particular points involved.

The principal rock in question is a bed of shale 8 feet thick, at Falcon Clints. It occurs 75 feet below the Whin, a series of limestones, sandstones, and shales intervening. It contains at some parts large numbers of approximately spherical nodules like peas. Thin sections show, in ordinary light, a grey groundmass in which are bedded grains of clastic quartz. In polarized light it is seen that this groundmass consists largely of an isotropic substance, in which lie numerous grains, rounded, irregular, or more or less definitely-bounded, of newly-formed quartz and some felspar. At parts these grains are so numerous and closely packed that they amount to a true interlocking mosaic, with very little isotropic matter. At other places they are more separated, and we get quite large spaces of the isotropic substance, but containing small flakes of mica and other things. These grains are not yet fully individualized; they are not water-clear, and have still so much dimness about them that they cannot be properly made out at all except in polarized light. They are absolutely distinguished from the original clastic material; not one of them could ever for a moment be mistaken for anything but a newly-formed secondary product.

The clastic quartz-grains remaining are seen to be all more or less attacked and corroded by the surrounding groundmass; their original angular outlines are in nearly all cases preserved, but the outer portions are no longer quartz, but an altered substance often containing a considerable amount of white mica and sometimes of felspar, whilst in some cases anthophyllite and andalusite are seen.

In the nodules considerable fields of clear, almost colourless, quite isotropic material are seen, in which bundles and sheaves and pseudo-spherulites of felspar, with some quartz, have been formed. Anthophyllite and andalusite are also seen in some of them.

Here, again, we have preserved for us one of those interesting cases of interrupted development. All the finer-grained material of the shale,—the impure micaceous mineral and the minuter quartz,—has been taken up into solution, or aqueous fusion; and out of the substance so formed a mosaic of quartz with some felspar, together with muscovite, has been in process of crystallization. But this process was arrested before it was complete, and so we are again able to see the unfinished stages, to observe the residual indefinite, isotropic, intermediate matter, and to note also the larger quartz-grains which were being attacked and dissolved, and would have all disappeared if the solution stage of the contact-action had been able to continue somewhat longer.

Sections from other parts of this bed show us mainly a fine-grained aggregate of newly-formed quartz and felspar, passing down into a quite cryptocrystalline felsitic-looking mixture (adinole), but opening up, on the other hand, here and there into numerous clear and glassy patches, which in polarized light are seen to consist of groups of well-twinned plagioclase felspar, which can often be identified as albite, whilst the extinctions also point to the presence of a species allied to oligoclase.

From the neighbourhood of Rowntree Beck, again, come specimens of shale altered to adinoles, and showing nodules up to two inches across, with anthophyllite.

We come now to the calcareous shales, and find that among these we have some of the most intensely altered rocks of all. Sometimes they occur as narrow bands in connection with purer limestones, sometimes as patches and lenticular masses in such limestones, and sometimes as thicker independent layers.

The most striking occurrence is at Falcon Clints. The specimens show a compact hornfels-like brown rock, with a jaspery sort of appearance and fracture. It contains many garnets of sufficient size to be easily seen with the naked eye. Thin sections show that these garnets are the most prominent mineral contained. They very much resemble those in the altered impure limestones round the Shap granite, and like them are polysynthetic and show a good deal of birefraction. They are, however, here not so often well-defined crystals, but more irregular grains and patches. They are often very much cracked, the cracks being infilled with chlorite and other substances. They occur irregularly, some parts of the rock being free from them and others containing swarms of small grains and crystals.

In some specimens idocrase occurs with the garnet, some of it as good large, well-defined crystals on which characteristic angles can be determined. It is nearly all quite fresh and good, and in every way of normal character.

Both garnet and idocrase crystals may be seen containing large numbers of small crystals of spinel, the garnet much more so than

the idocrase. No spinels are seen except as enclosures in those two minerals. The greater portion of them are of a good deep-green colour, and exactly resemble those seen in altered limestone of bombs from Somma; there are also colourless and pale reddish-brown crystals.

If we take several thin sections of specimens from this occurrence and average, as it were, the results of microscopic examination, we find that a large proportion of the rock consists again of a base or groundmass, which varies greatly in its texture and fineness of grain. Sometimes it is a close-grained, felsitic-looking mass, quite cryptocrystalline, and nothing definite can be made out as to its component minerals. At other parts it becomes coarser, and examination with high powers seems to show that much of it is quartz and felspar; this conclusion being confirmed when we come upon good-sized patches, like glassy spots in ordinary light, which with crossed nicols are seen to consist of well-twinned felspar with sometimes more or less quartz. This groundmass may be described as a calcareous adinole. In it are bedded many new minerals besides garnet and idocrase.

Wollastonite occurs at some parts in considerable abundance, mainly as radiating sheaves and bunches, with sphene, epidote, and recrystallized calcite. In some slides are well-developed chloritic "spots," as well as others of the pale yellow-green, almost quite isotropic, granular matter; and there are some which appear to be cordierite in early stages of development, corresponding exactly with similar spots seen to occur together with undoubted cordierite in other contact-rocks.

A large hand-specimen of this rock from Falcon Clints I have analyzed. It contains:—

Silica	53·80	per cent.	
Alumina	20·25	,,	
Ferric Oxide	8·15	,,	
Lime	3·27	,,	
Magnesia	3·02	,,	
Potash	2·32	,,	8·86
Soda	6·54	,,	
Water and Carbonic Acid	2·90	,,	
	100·25		

Another occurrence of a similar calcareous adinole is found at Sneblazes. A thin section shows the same sort of groundmass. No garnets or idocrase appear in the specimen examined, but there is a good deal of augite in small crystals, and felspar is again seen here and there. The analysis of this rock gives:—

Silica	50·60	per cent.	
Alumina	20·35	,,	
Ferric Oxide	8·30	,,	
Lime	7·75	,,	
Magnesia	2·58	,,	
Potash	2·39	,,	6·75
Soda	4·36	,,	
Water and Carbonic Acid	3·80	,,	
	100·13		

Another specimen of a like nature, from close to contact, near to Crag Lough, Bardon Mill, has the following composition :—

Silica	48·20	per cent.	
Alumina	17·30	,,	
Ferric Oxide	12·50	,,	
Lime	10·08	,,	
Magnesia	2·17	,,	
Potash	1·93	,,	6·52
Soda	4·59	,,	
Water and Carbonic Acid	4·05	,,	
	100·82		

It resembles the others in general composition, but shows hornblende among its new minerals.

It now remains to consider the sandstones, of which a large number have been collected from different points. There is not very much to be said about them, because when they are pure, or nearly so, the alteration is limited to a compacting and conversion of them more or less into quartzites; and where they are less pure, the interstitial matter has undergone the same alterations as have been above described. Thus, where there has been any noticeable amount of argillaceous deposit with the quartz-grains, it is now often seen to consist largely of the same mixture of new white mica and chloritic matter; and in this way we pass back again towards altered sandy shales, as the interstitial constituents increase.

It is noticeable, however, that whereas among the altered shales it is but seldom that brown mica is seen as a contact-mineral, and then only to a very subordinate degree, we find it more frequently and much more plentifully among the argillaceous sandstones. In one case from Rumbling Churn, near Dunstanburgh, there is as large a development of this biotite as might occur at any granite-contact, and all the characteristics of the mineral are the same.

In previous allusions to the contact rocks of the Whin Sill (Geol. Mag., April, 1895) I had occasion to refer to the interesting question of the supposed transfer of soda from the igneous rock to the altered shales, etc., in such cases of *basic* intrusions. I pointed out that observers of the contact-effects of such rocks elsewhere had been forced to come to the conclusion that such a transfer does often take place, a very considerable mass of chemical and other evidence rendering any other verdict difficult, or even impossible. Most of our knowledge on this point comes to us from German petrologists, though instances of altered rocks rich in soda are not lacking in this country.

When I commenced working at the petrology of the Whin Sill contact I naturally gave attention to this very important point, and it so happened that some of my first analyses, and separate determinations of alkalies in altered shales, very strongly confirmed the views expressed by the German authorities. In the course of the work I have made a considerable number of further determinations, the general result being that the answer obtained is not at all uniform in its direction. There are many of the shales in which soda

has increased very considerably; but there are also plenty of others in which this is not the case, even with highly altered rocks close to the contact, the normal excess of potash over soda having remained undisturbed; and the evidence, as will be seen, is rendered all the more contradictory by the fact that in a given vertical section of beds we may have a rock quite near the Whin, showing this chemically unchanged condition, whilst another one, further away from contact, shows a great increase of soda relatively to the potash.

As previously pointed out, the rocks along the Whin Sill are not specially favourable for the study of the chemical aspect of the metamorphism, inasmuch as the igneous mass is intruded parallel to their strike, and we cannot take any one bed at a distance and follow it gradually up to the contact. All we are able to do is to rely on the fact that, apparently without any exception, the normal shales of the Carboniferous show an excess of potash over soda within certain limits. All the trustworthy chemical evidence available shows this to be the case, and I have myself confirmed it by large numbers of careful determinations, published and unpublished, on specimens from various localities; the two latest being a fireclay and a shale which I took from the neighbourhood of Bardon Mill, near to the exposure of the Whin Sill and its contact-rocks, but quite outside the area of its metamorphic action. The alkalies contained are respectively:—

Potash	2·62 per cent.	and 2·66 per cent.
Soda	0·98 ,,	and 1·24 ,,

The three analyses given above of calcareous adinoles are all striking instances of a large increase in soda. The total alkali-contents are all three high, though not higher than may be seen in some cases of chemically normal shales. But soda far exceeds potash in all of them. No shales of similar composition exist outside the contact-zone, and however we may *explain* the transfer of soda, we cannot very well deny its occurrence. This increase of soda, as a chemical fact, is accompanied by the mineralogical fact of the appearance of albite in the altered rock. Had we these cases only before us, there would not seem to be much difficulty in accepting the statements of previous observers on the subject.

(*To be continued.*)

NOTICES OF MEMOIRS.

I.—Some Characteristic Genera of the Cambrian.[1] By G. F. Matthew, LL.D., D.Sc., F.R.S.C.

THE paper gives in brief the history and use of several generic names, and the distribution of certain species to which they have been applied. These genera have an important bearing on the antiquity of the *Olenellus* Fauna. *Bathyuriscus*, Meek, known as a Middle Cambrian genus in Montana and Nevada, occurs in the *Olenellus* Fauna of Eastern North America. It is nearly allied

[1] Paper read in Section C (Geology), British Association, Toronto, August, 1897.

to the following genus—*Dolichometopus*, Angelin, of the Upper *Paradoxides* Beds of Sweden, and is found in beds of similar age in Eastern Canada. With it is associated *Dorypyge*, Dames (=*Olenoides* in part of Walcott), which is a Middle Cambrian genus in Montana and is found also in the *Olenellus* Fauna of Eastern North America. *Microdiscus*, a genus of small trilobites, extending in Eastern Canada up to the Upper *Paradoxides* Beds, is found in the *Olenellus* Fauna. *Agnostus* has a peculiar development in the Upper *Paradoxides* Beds in the appearance at that horizon of the section *Lævigati*; the *Brevifrontes* also abound there. These two sections appear to be present in the fauna with *Olenellus*.

If we accept the view that there has been a regular development of the faunas through Cambrian time, it is difficult to understand how *Olenellus* can be at the base of the Cambrian succession and yet found in company with so many genera and subgenera which are known members of the Middle Cambrian fauna, or that of the Upper *Paradoxides* Beds. *Olenellus* has not yet been found below the *Paradoxides* Beds, and the evidence adduced indicates that it extended *above* rather than below this part of the Cambrian system.

II.—Problems in Quebec Geology.[1] By R. W. Ells, LL.D., F.R.S.C., of the Geographical Survey of Canada.

THIS paper is a brief review of the geological work done in the province of Quebec since the appearance of Dr. Bigsby's first paper on the geology of the province in 1827. It contains a short statement of the conclusions arrived at from time to time by the various workers in this field regarding the structure of the rock formations east of the St. Lawrence, as well as of the Laurentian complex to the north of that river. A summary of the latest views reached from the detailed study of these areas during the last fifteen years, which has appeared in the last volume of the Geological Survey's Report, is also presented.

In regard to the structure of the older crystallines north of the St. Lawrence and Ottawa rivers, it may be said that the opinion once held, that these rocks were originally of sedimentary origin, has now been greatly modified. The Laurentian rocks of Logan are now divided into two great groups. Of these, the lower is essentially a gneiss formation, and may be styled, for the sake of distinction, the Fundamental Gneiss. This is clearly older in point of time than the series of crystalline limestones, quartzose grey gneisses, and quartzite with which they are often so intimately associated as to render the determination of their true relations in the field difficult, but which at other points are clearly situated above the lower gneiss formation.

These newer gneisses and limestones, which have been styled by Logan the "Grenville Series," are, without doubt, for the most part of sedimentary origin, though they are invaded in all directions by masses of granite, greenstone, and other forms of igneous rock. As for the Fundamental Gneiss, also once supposed to be largely of

[1] Abstract of paper read in Section C (Geology), British Association, Toronto, 1897.

sedimentary origin, it has been very conclusively demonstrated, chiefly through the agency of the microscope, that this is for the most part at least an altered igneous rock, and that the supposed bedding planes owe their existence to other causes than those of sedimentation.

The original Upper Laurentian division, which included the great area of the Anorthosite rocks, also supposed at one time to represent altered sedimentary deposits, has been removed from the position it once occupied, since it has been proved, both by the evidence in the field and in the laboratory, to be of igneous origin and subsequent to the deposition of the limestone and quartzite series with which it is associated, so that the Grenville Series, according to the earlier view as to the succession of strata, may now be taken to represent the upper portion of the Laurentian system.

It may also be assumed to represent the lowest division of the clastic or sedimentary rocks in Canada. The relations of these to the rocks which have been styled the "Hastings Series" in Ontario are such that they may, in part at least, be regarded as portions of the same series which have been described in different portions of the field under different names; but whether these be regarded as belonging to the Laurentian or Huronian systems, is of small moment so long as their true relationship to each other and to the underlying Fundamental Gneiss is clearly understood.

To the east of the St. Lawrence the old dispute as to the age of the fossiliferous rocks near the city of Quebec, as well as of their relations to the crystalline schists of the mountain area in the interior of the province, may now be considered as satisfactorily settled. The former hypothesis by which the crystalline schists were regarded as the equivalents, in point of time, of the fossiliferous sediments of the St. Lawrence Valley has been clearly shown to be unfounded, and the schists of the Sutton Mountain area are now assigned to the Huronian system, or are at least beneath the lowest Cambrian of the district. The relative position of the several divisions of the fossiliferous Quebec group has also been ascertained, and it is now established that the Sillery division is situated stratigraphically beneath the Lévis, instead of being, as was at one time supposed, above it. As regards the age of the several divisions of the Quebec group (fossiliferous), it may be said that the Lévis is the apparent equivalent of the Calciferous formation, and that in its upper portion it approaches the Chazy; while the upper portion of the Sillery is the apparent equivalent of the Potsdam Sandstone formation. Between the upper Sillery and the great mass of the rocks which have been referred to this division, there is a fault of considerable magnitude, so that the lower portion of the Sillery presumably includes rocks which have been elsewhere classed as Cambrian, and these may extend as low as the *Paradoxides* zone or division of that system.

The areas of black slate and limestone, which, in the General Report for 1863, were regarded as beneath the crystalline schists and referable to the Potsdam formation, have been determined, on

the evidence of the contained fossils, to be much newer, and to be in fact the equivalents of the lower portion of the Trenton formation; and to this horizon may also now be assigned the greater portion of the strata in the city of Quebec. Here, however, there are a number of anticlinal folds, and the presence of certain fossils, similar to those obtained from the Lévis beds, indicates that along some of these folds beds of that horizon may be found. The same age may be assigned to the great extension of the black slates and limestones which occur at intervals along the south shore of the St. Lawrence, nearly to the extremity of the Gaspé Peninsula, and which appear to dip beneath the strata of the Sillery formation at many points.

In regard to the use of the term Potsdam a distinction must now be made between the Potsdam formation and the Potsdam Sandstone. The latter has been clearly proved in Canada to be the lower portion of the Calciferous formation, and is not separable from it, while there is a manifest break between this and the lower beds, or the Cambrian proper. The term Potsdam formation in Canadian geology was a comprehensive one like the term Cambrian, and like it included all between the Calciferous formation and the Huronian. The discriminate use of the terms has led to much confusion, and as the divisions of the Cambrian have now been properly determined the expression Potsdam formation has practically no meaning in Canadian geology.

REVIEWS.

MEMOIRS OF THE GEOLOGICAL SURVEY, SCOTLAND: THE GEOLOGY OF COWAL, including the part of Argyllshire between the Clyde and Loch Fine. By W. GUNN, F.G.S., C. T. CLOUGH, M.A., F.G.S., and J. B. HILL, R.N.; with Petrological Notes by J. J. H. TEALL, M.A., F.R.S., Sec. G.S., and Dr. HATCH, Ph.D., F.G.S. 8vo; pp. 333. with index, numerous illustrations in the text, and 10 plates. (Edinburgh: Neill & Co. Price 6s.)

THE Director-General of the Geological Survey observes, in his Preface to this Memoir, that the district known as Cowal "embraces the south-western extension of the various bands of metamorphic rocks which form the southern edge of the Highlands. Bounded on three sides by coast-lines, and penetrated by a number of sea-lochs, it affords better and more continuous sections of these rocks than are generally to be met with in the interior of the country. . . . . From the detailed study of this part of the Highlands much information has been obtained by the Geological Survey regarding the structures of the schists and the successive movements by which these structures have been produced. Originally most of the rocks described in the following chapters formed a thick series of sedimentary deposits, the geological age of which still remains to be determined. These strata have been found to have undergone a remarkable series of repeated movements. After being thrown into folds and having been cleaved so as to acquire a first

system of deformation, they have again suffered a repetition of the process more than once. They consequently represent secondary and tertiary, perhaps even quaternary, structures, probably due to mechanical movements with accompanying recrystallization. The regional metamorphism thus produced is not uniformly distributed, but seems to increase in intensity both from the south-east and north-west towards a nearly central line, ranging about north-east and south-west, which is an anticline of the foliation. It has not been traced to any intrusion of igneous rock, and is so general and diffused that it can hardly be regarded as in any sense a contact phenomenon. Where intrusive masses occur in the district they have given rise to their own accompanying alteration, quite apart from the general metamorphism of the whole area. These interesting and complicated structures, so well displayed in Cowal, are fully discussed in the present Memoir."

The Director-General further observes that "Mr. Clough, having mapped by far the largest part of the whole district, has had general charge of the Memoir, which is mainly written by him."

The extreme length of the district in question, from Ardlamont Point on the south-west to the granite edge in a north-easterly direction, is about 44 miles; with a breadth of about 18 miles from Toward Point on the Firth of Clyde to Otter Beacon on Loch Fine. The country is mountainous, though the elevations nowhere quite attain 3,000 feet, and may be said to decrease rather uniformly towards the south-west. By far the larger portion of the area is occupied by metamorphic rocks. Subjoined is a list of these, not to be regarded as representing a stratigraphical sequence.

Schists probably of Sedimentary Origin:—

Phyllites, including the two series of Dunoon and Ardrishaig, which consist of phyllites and thin limestones, mixed in the first series with schistose grits and in the second with quartzite schists.
Schistose grits and greywackes.
Quartzite schist or quartz schist.
Albite schist.
Garnetiferous mica schist.
Graphite schist.
Schistose limestones on various horizons, including the Loch Tay limestone.
Mica schist. Areas coloured thus in the maps may also include unseparated albite schists, sheared grits and greywackes, and phyllites.
Green beds: chlorite-epidote schists. The group lines may include some mica schists and schistose greywackes.

Igneous Rocks:—

Epidiorites, hornblende and chlorite schists, serpentine.

Besides the above a number of unfoliated igneous rocks occur intrusive in the schists.

The age of the schists, even in relation to each other, is not certainly known, but the different bands are seen to traverse the region in a north-east and south-west direction. The intimate structure of the rocks is described with much detail. Amongst the physical features of the more quartzose beds may be noted the occurrence of pebbles, mainly of quartz, felspar, or clay-slate. These pebbles have been subjected to a stretching action, which is supposed to have

taken place at the time of the production of the streakiness seen on the foliation planes of the adjoining phyllites, and probably both were accompaniments of the production of foliation. The elongation seems comparable to the distortion of fossils on the cleavage planes of slate.

The behaviour of the several groups towards the great central anticline of foliation presents some very interesting features. "In 'the anticline' folds (says Mr. Clough) with axes hading north-west, it is the under limbs of anticlines that have a tendency to be most thinned, whether we are on the south-east or north-west side of the centre of the anticline. Hence, if we regard the early 'pre-anticline' folds as having originally had axes hading north-west, the same law of the greater thinning of under limbs of anticlines prevails in both; and we may conclude that the source of the pressure which produced them both lay to the north-west of the area being described, and that the pressure was outwards from the Highlands in a south-east direction. The evidence in the north-west of Scotland is now well known to show that there were there, partly at all events in Post-Cambrian times, mountain-making forces pressing outwards from the Highlands in a W.N.W. direction. Hence the central Highlands represent an area from which earth-moving forces have pressed outwards, on the one side in a west-north-westerly and on the other side in a south-easterly direction."

The bulk of the schists are regarded as probably of sedimentary origin. Chapters iii and iv are devoted to a detailed description of them. The albite schists present some curious features. They occur mainly towards the anticline centre, and at Lochgoilhead all the more micaceous schists contain albites. The albite spots are almost confined to the micaceous and chloritic beds, and it is doubtful whether they occur at all in the more quartzose pebbly beds. It is inferred from their never showing any appearance of stretching that the albites are of later age than the mass of the movements affecting the rocks in which they occur.

The "Green Beds" present another curious group of rocks. These are of a mixed and variable character; for on the north-west side of the anticline about one-half of the group consists of other schists, whilst on the south-east side the different outcrops are comparatively unmixed. They are described for the most part as epidote-chlorite schists, and are often intersected by thin quartzose veins coloured green by epidote [? the "epidosite" of Sterry Hunt].

Of the schistose igneous rocks, the epidiorites, hornblende schists, and related chlorite schists, associated with the presumed sedimentary series, are most abundant towards the side of Loch Fine. They are generally harder than the schists, and thus help in working out the physical structure. It is believed that they represent old intrusions rather than lava-flows. There is a special danger of confusing some of these old igneous rocks with the "green beds." In the area between Stralachlan and Loch Fine, these epidiorites, etc., form huge irregular masses behaving on a large scale like sills with irregular protrusions, the longer axes of which coincide with the strike of the main mass, and of the quartzites in which they are

intruded. Mr. Teall gives the following description of their appearance under the microscope: "Uralitic hornblende, a saussuritic aggregate of water-clear felspar and granular epidote, irregular patches of sphene (leucoxene) and aggregates of chlorite."

In chapter vii the minerals of the schists are enumerated and partly described, whilst much attention is paid to the direction of stretching. Chapter viii is devoted to the general physical structure of the schists, together with remarks on metamorphism. The most conspicuous feature of the schist area, as may be inferred from previous remarks, is the great anticline of foliation running in a direction about 35° W. of S. through the heads of Loch Goil, Loch Striven, and Loch Riddon, and the hills about a mile north-west of Tighnabruaich. There is no doubt that this anticline is a true arch of an early foliation; but scarcely perhaps an anticline of bedding. The authors (and more especially Mr. Clough) apparently conclude, after much weighing of the evidence, that at least five of the groups on the north-west side of the anticline are unrepresented on the south-east side, notwithstanding some apparent points of resemblance.

Lines of actual rupture contemporaneous with the schist-making, comparable to the "thrusts" of the north-west of Scotland, probably do not occur anywhere in Cowal, except on the smallest scale, such as strain-slips with throws not exceeding a few inches. The numerous faults which have been mapped and which have effective throws, are all later than the schist-making, and break up the minerals and planes of schistosity instead of helping to form them. To the question regarding the agents which produced the general metamorphism of the district, Mr. Clough considers that it would be premature to reply; but he does not consider that there is any exposure of igneous rock which would account for it. The alteration effected by the Glen Fine granite, for instance, does not extend for more than a mile, and is of quite a different character.

The direction of the boundary fault between the Schists and the Old Red Sandstone is nearly parallel to that of the centre of the anticline. This fault cuts off a shred of Upper Old Red Sandstone rocks, which thus appear at the extremity of the peninsula that terminates in Toward Point. They consist, in the main, of red breccias and sandstones mixed with occasional blood-red and variegated shales; calcareous sandstones and magnesian limestones are numerous on a certain horizon. One of the sections which best illustrates the relations between the red marls and the metamorphic schists occurs on the shore just to the south of Inellan pier.

Chapters x to xiv are devoted to the igneous rocks (unfoliated). A small part of the igneous complex of Garabhal Hill, etc., comes within the district. These are, in fact, granitites with a tendency to pass into a coarse dioritic rock; the granitic rocks are generally characterized by abundant porphyritic crystals of orthoclase felspar. Considerable attention is paid to the character of the metamorphism near the edge of the plutonic rock, chiefly with a view to contrast the metamorphism special to its neighbourhood with that further away near the anticline of Cowal.

Hornblende-porphyrites and felsites are classed together, since the same porphyritic constituents, viz., felspar, black mica or chlorite, sometimes hornblende, and scattered quartz blebs, occur in both. These rocks behave in the field in the same way as the lamprophyres (presently to be mentioned), generally forming sheets which run roughly with the foliation of the schists; they are of limited extent. An intrusive boss of some importance is also described as hyperite, the rock consisting of hypersthene, augite (diallagic in part), plagioclase (more or less lath-shaped), iron-ores, and interstitial quartz.

Of the older igneous rocks are those described under the terms lamprophyre and mica-trap. It is only when the mica is macroscopically prominent that the latter term seems applicable. By a gradual decrease in the amount of mica the mica-dolerites may pass into rocks of more normal doleritic aspect. In all these early dolerites which have been examined the augite differs from that of the Tertiary basalts in belonging to the pale form, malacolite, and for the most part occurring porphyritically. In the north and east of Cowal these lamprophyres are exceedingly numerous, but they are not known within a distance of four or five miles of the Upper Old Red Sandstone boundary. They rarely form vertical dykes; when they do so, these dykes usually run in a different direction to that of the basalts. Most frequently they occur as sheets with varying and not very steep hades to the horizon. They do not keep to the bedding or foliation of the schists, but may be constantly seen cutting across their crumplings. It is evident that all the movements in connection with the foliation of the schist had ceased before their intrusion. Though thin and inconstant, the lamprophyres are of considerable interest in working out the geological structure of the district, and a greater help than the basalts. This is because the majority of the faults are of later date than the lamprophyres, and throw them, so that they help to indicate the different faults and even the amount of their respective throws, independently of the schists.

An inspection of the geological map will show that parts of Cowal are seamed by basaltic dykes: this subject is very fully treated in the Memoir. Basalts, dolerites, and tachylites constitute the group, with which even augite-andesites are included. Thin margins or selvages of distinctly glassy rock, tachylite, are common, but not to be found without close search. One of the most curious features of basaltic dykes, especially noticeable on the coast, is the tendency for some to weather in relief, whilst others form recesses sometimes hollowed out into caves. The authors consider that the size of the grain is often a determining factor in these cases. The intimate structure of the basaltic rocks is treated of at considerable length.

With respect to the relative age of the dykes, the broad east-and-west dykes are regarded as older than the basalts having a north-west direction. "If we suppose the early east-and-west dykes to be of Carboniferous age, the interval of time between them and the north-west dykes must be immense; for there can be no doubt that many of the latter belong to the same set as those which, still with a north-west direction, are seen in the island of Mull to intersect

the bedded basalts of Tertiary age." The very conspicuous east-and-west dykes at Ardlamont Point are not crossed by any running north and south; but, since these are regarded as continuations of the two large dykes crossing the island of Bute, where one of them is clearly cut by later Tertiary dykes, we may infer that the Ardlamont dykes are of earlier date than the Tertiary period. Similar conclusions result from the detailed examination of other districts. Within this area only five intrusions have been recognized as trachyte: these are all dykes, which are considered to be later than the basalts.

Three chapters are devoted to the general geological structure of particular districts, and the numerous sections given in the text are of great service to the readers in this connection. The structure of the country about Lochgoilhead, for instance, is particularly interesting on account of its proximity to the anticline. Moreover, since the much frequented coach-road through Hell's Glen traverses this region, it enjoys the advantage of being easily accessible.

Two chapters, illustrated by a special map (Clough), are devoted to Glacial deposits. The following features are indicated in the map:—(1) Landslips; (2) marine and fresh-water alluvia and peat in basin-shaped hollows; (3) boulder-clay and sandy drift without definite moraine shapes; (4) drift with well-defined moraines. The direction of the striæ ranges from S.W. through S. to S.E., with few exceptions.

The remaining chapters deal with such subjects as marine and fresh-water alluvia, peat, landslips, blown sand, prehistoric remains, geological aspects of the scenery, and economic resources.

In the appendix Mr. Teall makes some general remarks on the petrography of the district. After insisting on the well-known fact that, in a complex series of stratified deposits, the coarser-grained sediments retain traces of their original character long after all such traces have disappeared from the finer-grained deposits, he proceeds to illustrate the point with reference to the gneissose grits (the schistose grits and greywackes of the Memoir) so largely developed in the Southern Highlands. Although distinctly gneissose in structure and composition, they differ markedly from igneous gneisses in their relation to the other rocks with which they are associated, and frequently contain relics of original grains of quartz, often bluish in colour, and felspar. The rocks of this class are crystalline schists essentially composed of quartz, felspar, and one or two micas: they are therefore gneisses in the usual sense of the term. Where conspicuous traces of their clastic origin remain they may be termed gneissose grits; when all, or nearly all, such traces have disappeared they may be termed granulitic gneisses: they pass by insensible gradations into felspathic mica schists.

Plates i to v are reproductions of photographs of Natural Rock Exposures, taken by Mr. R. Lunn. The Geological Survey of Scotland is to be congratulated on these most effective pictures of contortion, which are at once instructive and picturesque. The other plates are likewise very good of their kind, and the volume generally may be deemed a most satisfactory contribution to geological literature.

REPORTS AND PROCEEDINGS.

Geological Society of London.

I.—December 15, 1897.—Dr. Henry Hicks, F.R.S., President, in the Chair. The following communications were read:—

1. "On the Pyromerides of Boulay Bay, Jersey." By John Parkinson, Esq., F.G.S.

After briefly noticing the literature of the subject, the author describes the altered rhyolites of Boulay Bay. One variety, the commonest, is of a dark-red colour, showing flow-structure; another is porphyritic; a third, near the centre of the Bay, has a pale-greenish matrix enclosing fragments, which, however, are due to flow-brecciation. Large pyromerides occur in two localities; in the more interesting, that north of the jetty, the structure of the rock indicates either a very peculiar magmatic differentiation *in situ* or (more probably) the mixture of two magmas differing in their stage of consolidation.

From study of a series of specimens of the pyromeridal rock, the author arrives at the following conclusions:—(1) The rock shows marked flow-structure and at times bands which indicate a slight difference in its composition, the latter tending to assume a moniliform outline. In such the microscopic structure corresponds with that of the pyromerides, and exhibits traces of radial crystallization. (2) These afford a passage into somewhat oval pyromerides, with rather tapering ends and irregularly mammillated surfaces. (3) From these sometimes a single one seems to be thrown off, while lines of pyromerides or little lumps of similar material are scattered about the matrix. (4) Many of the pyromerides are solid throughout; others have a central cavity filled with quartz.

The author describes varieties of the pyromerides. They are generally deep-red in colour, and exhibit (*a*) fluxion-structure, made more distinct by minute black microliths; (*b*) a radial structure; (*c*) a "patchy" devitrified structure (with crossed nicols);—the second (*b*) being not always present. The matrix is usually of a greenish tint, showing devitrification-structure and sometimes a trace of perlitic structure.

The pyromerides frequently exhibit more or less crescentic cracks, due apparently to contraction, which have been filled by quartz. Sometimes also they scale off in rudely crescentic shells. In one locality a variety with good spherulites, about as large as a pea, passes into one showing a fluxion-structure and pyromerides, having traces of radial structure as well as clots and irregular "wisps," suggestive of a stiffer material broken up by one more liquid.

As the result of his studies, the author thinks that while very regular spherulites do occur, apparently in consequence of radial crystallization round a centre, the pyromerides are due to the mixture of two magmas slightly different in composition and fluidity, the less plastic of the two being sometimes drawn out into streaks, but at others forming lumps, in which, where their form is suitable, a radial

structure is subsequently developed. He concludes by comparing the pyromerides of Boulay Bay with specimens from other localities described by MM. Delesse and Lévy, Professor Iddings, and Miss Raisin, or collected by himself, and by discussing the quartz-filled cavities which occur in certain cases. These he regards as originally vesicles, and not due to any subsequent decomposition.

2. "On the Exploration of Ty Newydd Cave near Tremeirchion, North Wales." By the Rev. G. C. H. Pollen, S.J., F.G.S.

In November, 1896, a Committee was formed, consisting of Dr. H. Hicks, Dr. H. Woodward, and the author, for the purpose of exploring this cavern, which is situated in the same ravine on the east side of the Vale of Clwyd as the well-known caverns of Ffynnon Beuno and Cae Gwyn, explored about twelve years ago by Dr. H. Hicks and Mr. E. B. Luxmoore. Grants have been made by the Royal Society and by the Government Grant Committee for the purpose of carrying on the explorations; and though a considerable time must elapse before the work is completed, the results already obtained are of so much importance that the author has thought it advisable to bring them before the Society. In the work of exploration he has throughout been ably assisted by the theological students of St. Beuno's College. The cavern had been in part broken into by quarrying operations, but the chambers and tunnels were completely filled up with more or less stratified deposits, and had remained entirely untouched.

Although the ground above the cavern is strewn over with drift and erratics from the North and from the central areas of Wales, not a fragment of anything but immediately local material has been discovered in the cavern itself, showing clearly that the deposits in the cavern had been carried in by water before the Northern and Western ice had reached this area. The work has been carried on almost continuously throughout the year, and most of the material has been removed for a distance of over 60 feet from the entrance. The height of the cavern above sea-level is 420 feet, or about 20 feet above the floor of the Cae Gwyn Cave.

The following points appear to the author to be now fully established:—

(1) The material in the Ty Newydd Cave, as in the lower parts of those of Ffynnon Beuno and Cae Gwyn, is of purely local origin. Of this he can speak with confidence, as the question was before him from the beginning, and the gravels were examined with minute care for erratics.

(2) This local deposit is of earlier date than the Boulder-clay with Western and Northern Drift. This was proved by the finding of granite- and felsite-boulders abundantly at higher levels and over the cave, and in one case filling the upper part of one of the fissures communicating from above with the cavern.

(3) The occurrence of the tooth of a large mammal (*Rhinoceros*) in the lower part of the cave shows that the animal was contemporary with, or of earlier date than, the infilling of the cavern by the local drift.

II.—January 5, 1898.—Dr. Henry Hicks, F.R.S., President, in the Chair.

Professor Judd drew attention to the outline geological maps of England and Wales on the scale of 30 miles to the inch, for the use of schools and colleges, presented by John Lloyd, Esq. These were reproduced, by permission of the Science and Art Department, from the maps in use at the Royal College of Science, South Kensington.

The following communications were read :—

1. "On the Structure of the Davos Valley." By A. Vaughan Jennings, Esq., F.L.S., F.G.S.

Evidence is brought forward to show that the level area, about four miles in length, near Davos is occupied by superficial deposits, and that the lateral talus-fans there have been cut through at a relatively recent date since their accumulation; that the northern end towards Wolfgang is blocked by moraine-material of great thickness, but for which the Davoser See would drain north to the Landquart, carrying with it the waters of the Fluela and Dischma; that the contour-lines suggest the former existence of a far larger lake stretching south towards Frauenkirch, and that in that part there is proof of the previous existence of a great detrital fan sufficient to account for the existence of the lake in question.

It is shown that the former ice-movement was not from the present watershed between the tributaries of the Landwasser and Landquart, but from a spot farther south.

The author concludes that the main valley-systems were marked out in Pre-Glacial times, and that at one time there was a watershed somewhere between Davos Platz and Frauenkirch. During the Glacial Period moraine-material was heaped up across the valley below the Hörnli, and held up the waters to the south, forming a great lake of which the present Davoser See is a relic, the outflow being probably over a low saddle near the present Wolfgang; during this time a great moraine and detrital fan existed across the valley to the south, and the lake for a long time was thus prevented from draining in that direction. After the Glacial Period the northern moraine was subjected to little erosion, but the southern one, formed from the first of looser material, was rapidly cut back by the Sertig Bach, and in time the barrier was so weakened as to cause that end of the lake to be tapped, and at that time the terraces opposite Frauenkirch may have been levelled, while the flow over Wolfgang would be stopped, and the Fluela and Dischma streams turned southward; the Landquart would then cut away the margins of the talus-fans which had been accumulating in the lake.

2. "Sections along the Lancashire, Derbyshire, and East Coast Railway between Lincoln and Chesterfield." By C. Fox-Strangways, Esq., F.G.S. (Communicated by permission of the Director-General of H.M. Geological Survey.)

The portion of the line considered in this paper occupies a distance of about forty miles, and runs nearly at right angles to the strike of all the beds from the Lias to the Coal-measures.

The lower part of the Lias and the Rhætic beds are entirely concealed; but grey marls overlying red marls occur about half a mile east of Clifton Station, and at the station the Red Marl of the Keuper comes on in force. The alluvial deposits of the Trent, pierced to a depth of from 25 to 30 feet, consist principally of loam overlying varying thicknesses of sand and gravel. Horns of red deer were found at a depth of 25 feet. At Dukeries Station white flaggy Keuper sandstones appear from beneath the Red Marl, and probably represent the eastward extension of the Tuxford Stone. A deep well here has been bored to a depth of 644 feet from the present surface, and details of the section are given in the paper. South of Kirton there is a deep cutting in the Waterstones, and after leaving the escarpment the line enters on the great dip-slope of the Bunter Pebble Beds, which are shown at Ollerton and at intervals for four miles beyond this. There are no sections in the Lower Red and Mottled Sandstones; and west of Warsop the line crosses the dip-slope of the Magnesian Limestone. Details of the sections in this rock are given.

Between Scarcliff and Bolsover the line crosses the Permian escarpment in a tunnel, the whole of which is in the Coal-measures; these are high up in the series, and contain no coal-seams of value. They are not stained red.

West of Arkwright's Town Station is a very complete section of beds representing the Middle Coal and Ironstone series (the most valuable part of the Derbyshire Coalfield), of which full details are given, most of the important coal-seams being readily recognized; and the author describes some remarkable features in the relationships of some of the sandstones to the other deposits.

The absence of Glacial beds is of much interest; not a trace of genuine Boulder-clay has been seen along the whole line.

OBITUARY.

GEORGE HARRY PIPER, F.G.S.

Born April 8, 1819. Died August 26, 1897.

The subject of this brief notice, the second son of the late Captain E. J. Piper, R.N., was born in London in 1819, in the neighbourhood of Regent's Park, where his family resided. His parents removed to Herefordshire in 1829, taking their son George, then a boy of ten years old, with them. Naturally an observant youth, country life and pursuits, after London, had a great attraction for him, and he speedily became interested in studying the birds, trees, and flowers, and early learned to fish and shoot. When only fourteen, however, his health gave way, and he had to remain in bed for about three years, suffering from a lame leg, and was never entirely free from pain during the remainder of his life. As a consequence of this, his education was carried on at home, in a more or less desultory manner. Nevertheless, he was a keen

scholar, and at about eighteen years of age he was duly articled to the late Mr. Thomas Jones, Attorney of Ledbury; and having served his master and duly passed his examinations in law, he was admitted as a Solicitor in 1849, and from that time commenced to practise in Ledbury, where he continued in his profession until his death. He was joined in partnership by Mr. C. E. Lilley in 1886, and was one of the oldest solicitors in the county. In addition to his private practice he also held appointments as Commissioner to Administer Oaths, Perpetual Commissioner, etc., Deputy-Registrar, and in 1865 Registrar, of the County Court and High Bailiff of the Court, which offices he held up to the time of his death.

Mr. Piper took a keen interest in the progress and work of the Horticultural and Natural History Societies of the County of Hereford, and had filled the position of President both of the Woolhope Naturalists' Field Club and the Malvern Naturalists' Field Club. To these Societies he communicated many papers, and with them he did much excellent work in botany, local archæology, and geology, more especially in the latter field of research.

Mr. Piper's geological work was carried on for years in association with the late Rev. W. S. Symonds, M.A., F.G.S., of Pendock Rectory, Tewkesbury; Dr. Bull of Hereford; the Rev. P. B. Brodie, M.A., F.G.S., and other enthusiastic workers.

The greatest geological achievement performed by Mr. Piper was the carrying out successfully, after many years of patient exploration, the complete examination and recording, foot by foot, of the famous section near the railway tunnel at Ledbury, comprising the series of deposits from the Aymestry Limestone, through the Upper Ludlow rocks; the Downton Sandstone, with *Pterygotus*; the Ledbury shales, consisting of red, grey, purple shales, and grey marl-beds, with *Pteraspis*, *Auchenaspis*, *Cephalaspis*, *Onchus*, *Pterygotus*, *Lingula cornea*, etc.; followed by Lower Old Red Sandstone, with *Pterygotus*, *Pteraspis*, and *Cephalaspis*, etc.

In Mr. Symonds' paper "On the Old Red of Herefordshire" he writes of the Passage-Beds at Ledbury: "Having again visited Ludlow, and compared the Passage-beds of that district with those of Ledbury, I am convinced that nowhere perhaps in the world is there such an exhibition of Passage-beds presented to the eye of the geologist as at the Ledbury Tunnel on the Worcester and Hereford Railway." See H. Woodward's "Brit. Foss. Crustacea" (*Merostomata*): Pal. Soc., part iii, 1871, p. 99.

The rich collection of fossils which Mr. Piper formed from the Ledbury Tunnel Section, and from other localities in the neighbourhood, will, it is believed, shortly find a home in the British Museum (Natural History), Cromwell Road, where so many of his fine Cephalaspidian fishes have already been presented in past years, including the superb group of twelve individuals of *Cephalaspis Murchisoni*, preserved in one block of Old Red Sandstone—forming Plate x in Mr. Arthur Smith Woodward's Catalogue of Fossil Fishes in the British Museum (Natural History), Part ii, 1891, p. 189—